10-047-009 (REV. 6/63)

DIVISION SNAP-8
TM 4933:65-8-311
DATE 3 August 1965
W.O. 0741-66-2000
CR-72211

TECH... MEMORANDUM

AUTHOR(S): A. J. Sellers, M. K. ...

TITLE: EXPERIMENTAL INVESTIG... FORCED CONVECTION ONCE-THROUGH MERCURY BOILE... MANCE CHARACTERISTICS

STRACT

Once-through type mercury bo... performance characteristics were studied experimentally in a single tube Nak... mercury heat exchanger of concentric counterflow configuration. Heat t... and two-phase flow pressure drop data were obtained for different mercury ... passage inlet end plug insert geometries. The experimental data were evaluat... determine the validity of proposed sing... empirical boiling heat transfer and ... phase flow pressure drop correlations. (1)

a. The initial boiler perfo... ce characteristics are dependent on the mercury flow passage internal wall ... ce conditioning state and the thermal and dynamic conditions imposed by the ... ow passage internal geometry.

b. Elevated liquid phase ... flow velocity at the preheat section end point combined with similar dyna... conditions in the low vapor quality section demonstrates excellent boi... nditioning effect when the mercury flow passage is cleaned by establishe... s prior to mercury injection.

c. The boiling heat transf... tes obtained from a fully conditioned boiler are in close agreement with ... redictions established by the dropwise dry wall boiling heat transfer cor... ons.

d. The two phase flow pre... drop data are correlated by means of the product (ϕf_v) in terms of a ... d Martinelli parameter (X) as proposed by Reference (1).

e. The introduction of a ... preheat section plug insert geometry providing elevated liquid velocity ... improved the boiler performance stability very significantly.

APPROVED:

DEPARTMENT HEAD E. Eber

NOTE: This document is considered ... inary and is subject to ... analysis progresses and additional ... are acquired. The general reader may encounter internal reference not a... le to him.

CONTENTS

I. INTRODUCTION

Once-through type boiling liquid metal heat transfer rates and associated two-phase flow dynamics have been the subject of a large number of experimental and theoretical studies during the past decade since the initiation of the development of various Rankine cycle SNAP power conversion systems. Difficulties were encountered in achieving rated boiling heat transfer fluxes in NaK heated once-through mercury boilers. These difficulties were encountered to various degrees in mercury flow passages made of 316 SS, Haynes-25 and 9Cr-Mo alloys. Regardless of the material used for the mercury flow passage, some of these boilers demonstrated initial performance characteristics up to design expectations although the length of the required conditioning period varied. Others did not approach the design expectations after hundreds and even thousands of hours of continuous operation. This was believed to be caused by nonwetting, surface contamination, and/or liquid phase slug formation due to absence of early vortex flow establishment in the flow passage next to the liquid-vapor interface.

Several supporting programs were conducted in conjunction with SNAP-8 boiler development activity to investigate these possible causes. The effects of additives on wetting during mercury pool boiling heat transfer were evaluated[2]. On the basis of the results of this study, rubidium was added to the mercury in amounts up to 860 ppm. The predicted boiling heat transfer rates were achieved after addition of the Rb in a SNAP-8 full-scale boiler initially operating at a highly deconditioned state for several hundreds of hours. To investigate the effect of elevated liquid phase vortex flow velocity on the overall boiler performance, a tight preheat section plug insert geometry, providing a liquid phase velocity of 7.0 ft/sec, was initially tested in an experimental boiler originally performing in a deconditioned state. The results showed immediate improvement in obtained boiling heat transfer rates and the boiler performance stability. The boiling heat transfer rates as represented by the boiler NaK

NOTE: Superscript numbers in parentheses refer to similarly numbered references listed following the text.

temperature profile approaches the design expectations. The boiler exit pressure fluctuations were reduced to a negligible value. This initial qualitative evidence prompted further investigation of the SNAP-8 boiler design concepts.

II. PURPOSE

The object of this experimental study is to investigate the thermal and dynamic performance characteristics of different "once-through" type boiler plug insert geometries.* The availability of design data in this area is very limited, yet these data are very important in controlling the thermodynamic behavior of a boiler such as that used in SNAP-8 and similar Rankine cycle power conversion systems. Since most of these boiler initially exhibit deconditioned boiler characteristics to some extent, it is of particular interest to investigate the effect of different working fluid dynamic aspects in the plug insert section. Initial positive evidence of qualitative value warranted further investigation into this boiler design area.

III. DESCRIPTION OF TEST APPARATUS

A. LOOP DESCRIPTION

CL-4 was designed to simulate the SNAP-8 dynamic cycle conditions for corrosion study. It is a three-loop system, which consists of a heated primary circulation NaK loop, coupled through a boiler simulated mercury Rankine-cycle loop which in turn rejects its heat through the condenser to an air cooled circulating NaK loop. The following operating ranges were used for the boiler plug insert experiment:

NaK Primary Loop

Boiler inlet temperature	1,330°F
NaK flow rate	2,050 lb/hr max.
Heater power input	35 kw max.

Mercury Loop

Mercury flow	500 lb/hr nominal
Boiler inlet temperature	500°F
Boiler inlet pressure	500 psia max.
Boiler outlet pressure	100 psia min.

* Such a geometry consists of a helically wound wire on a solid bar closely fitted and inserted in a mercury tube. The resulting flow passage is of a helical pattern.

Figure 3.1 is the flow diagram of the loop and Figure 3.2 is the schematic arrangement of the loop. The three loop system was constructed to high-vacuum standards.

1. Primary NaK Loop

The NaK primary loop employs a direct resistance heater in which low voltage electrical current is passed through the NaK carrying tube and the NaK. The heater is in a coiled configuration with the two grounded leads on the loop side and an insulated low voltage lead at the mid-point of the coil. Since the resistance of each leg is fixed, the power input is varied by controlling the voltage across the terminals. The voltage is regulated with a saturable core reactor transformer. An electromagnetic pump maintains the NaK flow which is measured by a magnetic flowmeter. A purification system is employed to reduce and maintain the system's oxide level to less than 25 ppm. Other major components in the loop include a level indicator, expansion tank, dump tank, and a cover gas system.

2. NaK Condensing Loop

Major components of the NaK condensing loop consist of a conventional air cooled finned tubes heat exchanger, a magnetic flowmeter, and an electromagnetic pump. A convective type cold trap is employed to maintain a low oxide level in the loop.

3. Mercury Loop

The mercury loop uses two Chempump* Model CFHT-7 1/2-65 (one on a standby basis) for pumping the liquid mercury. A venturi flowmeter is used to measure mercury flow rate. Two semi-standard valves are used for control purposes and for imposing a resistance between the pump and boiler. An adjustable choked nozzle is located downstream of the boiler outlet for the regulation of boiler outlet pressure. The adjustable choked nozzle is a convergent-divergent nozzle in which the throat area may be varied with a moveable pintle. The mercury vapor is then passed through a desuperheater and a turbine blade mockup section before

*Manufactured by Chempump Division of Fostoria Corp., Huntingdon Valley, Penn.

entering the condenser. The desuperheater and the blade mockup are not necessary for the boiler experiment, but were originally designed for corrosion study. The NaK-cooled mercury condenser is a counter-flow heat exchanger consisting of three tapered condensing tubes with a straight length for subcooling.

The rest of the mercury loop consists of semi-conventional liquid metal components such as bellows sealed valves, electrical resistance level probes and a cover gas system.

B. BOILER DESCRIPTION

The mercury boiler is single-pass counter-flow tube-in-shell heat exchanger wound into helix form with a protruding inlet and outlet. Figure 3.3 shows the boiler. The mercury flows in the tube and the NaK through the annulus passage. An inlet plug is inserted into the straight part of the protruding mercury inlet section to increase the liquid mercury and low quality helical velocity. A spiral wire vortex-generator is installed in the coiled mercury tube to promote heat transfer. Spacers are used to center the mercury tube in the annulus. The NaK inlet and outlet are located near the ends of the shell. The boiler configuration and geometry are as follows:

Mean helical coil diameter --- in	18
Helical shell pitch --- in	1-3/8
Shell size --- in	1-1/8 O.D. x 0.083 wall x 9.959 I.D.
Tube size --- in	9/16 O.D. x 0.0832 wall x 0.397 I.D.
Vortex wire diameter --- in	0.049
Vortex wire pitch --- in	1.5
Coil tube length --- ft	55
Straight tube length --- ft	5
Tube material	9 CR-1Mo
Shell material	316 SS

The boiler was installed in a metal tank assembly and insulated with about 6-1/2 inches of fused alumina bubbles. Six 1/2 in.-thick layers of fiberflax insulation was affixed to the outside of the boiler supporting tank assembly. The test runs and corresponding plug insert geometries tested are listed in Figure 3.4.

C. BOILER TEST INSTRUMENTATION

1. Temperature Measurement

The NaK boiler inlet, outlet, and the boiler shell temperatures are measured by 1/16" diameter, stainless steel sheathed, MgO insulated thermocouples. These thermocouples have ungrounded junctions, and are attached to the 316 stainless steel tube as shown in Figure 3.5. The NaK boiler inlet temperature is measured by three thermocouples attached circumferencially at the tube 18" from the boiler. The boiler outlet temperature is measured by a thermocouple located at about 9" from the boiler shell. Location of thermocouples along the 60 feet boiler is as follows:

Thermocouple No.	Distance from Boiler Inlet Tube Sheet (in.)	Remarks
1	35.5	Straight section
2	40.5	"
3	45.5	"
4	50.5	"
5	55.5	"
6	60.5	"
7	75.5	"
8	116.5	Coiled section
9	154.5	"
10	201.5	"
11	227.5	"
12	268.5	"
13	306.5	"
14	350.5	"
15	390.5	"
16	427.5	"
17	460.5	"
18	570.5	"
19	592.5	"
20	639.5	"
21	669.5	"

Thermocouple No.	Distance from Boiler Inlet Tube Sheet (in.)	Remarks
22	718.5	Coiled section
23	732.5	"
24	733.5	"

The mercury inlet and outlet temperatures are also measured by Chromel-P-alumel 1/16" diameter, MgO insulated, stainless steel sheathed ungrounded thermocouples. The boiler inlet thermocouple is welded to the tube wall 10" from the boiler inlet. The boiler outlet temperature thermocouple is an immersion type installed 15" downstream of the boiler as shown on Figure 3.6.

Four Pace 150°F reference junctions are utilized to condition the thermocouple signal. The NaK shell temperatures are recorded on a Leeds and Northrup 24 point 0-1500°F. 12" scale strip chart recorder. The NaK boiler inlet temperature is recorded on a Daystrom Weston 24 point, 150°F.-1500°F. 4" scale strip chart recorder. The NaK boiler and the mercury boiler outlet temperature are recorded each on Motorola 2 point, 150°F.-1500°F. 4" scale strip chart recorders.

2. Temperature Measurement Accuracy

The thermocouples carry a manufacturers accuracy guarantee of ± 4°F from 0°F to 530°F, and ± 3/4% above 530°F. The Leeds and Northrup and Daystrom Weston records are periodically calibrated against a Leeds and Northrup portable potentiometer standard to an accuracy of 1/4% of full scale. The Motorola temperature recorders are setup to an accuracy of 1% of full scale, but overall readout accuracy is judged to be approximately 2%.

3. Pressure Measurement

The boiler inlet, outlet, and the two pressure taps in the instrumented plug are measured by 0-500 psia range, unbonded type strain gage transducers. Solid state stable bridge supplies provide 6 v, dc exatation to each transducer. The output signal from each transducer is amplified to the desired level and transmitted to the indicators. These pressure readouts are

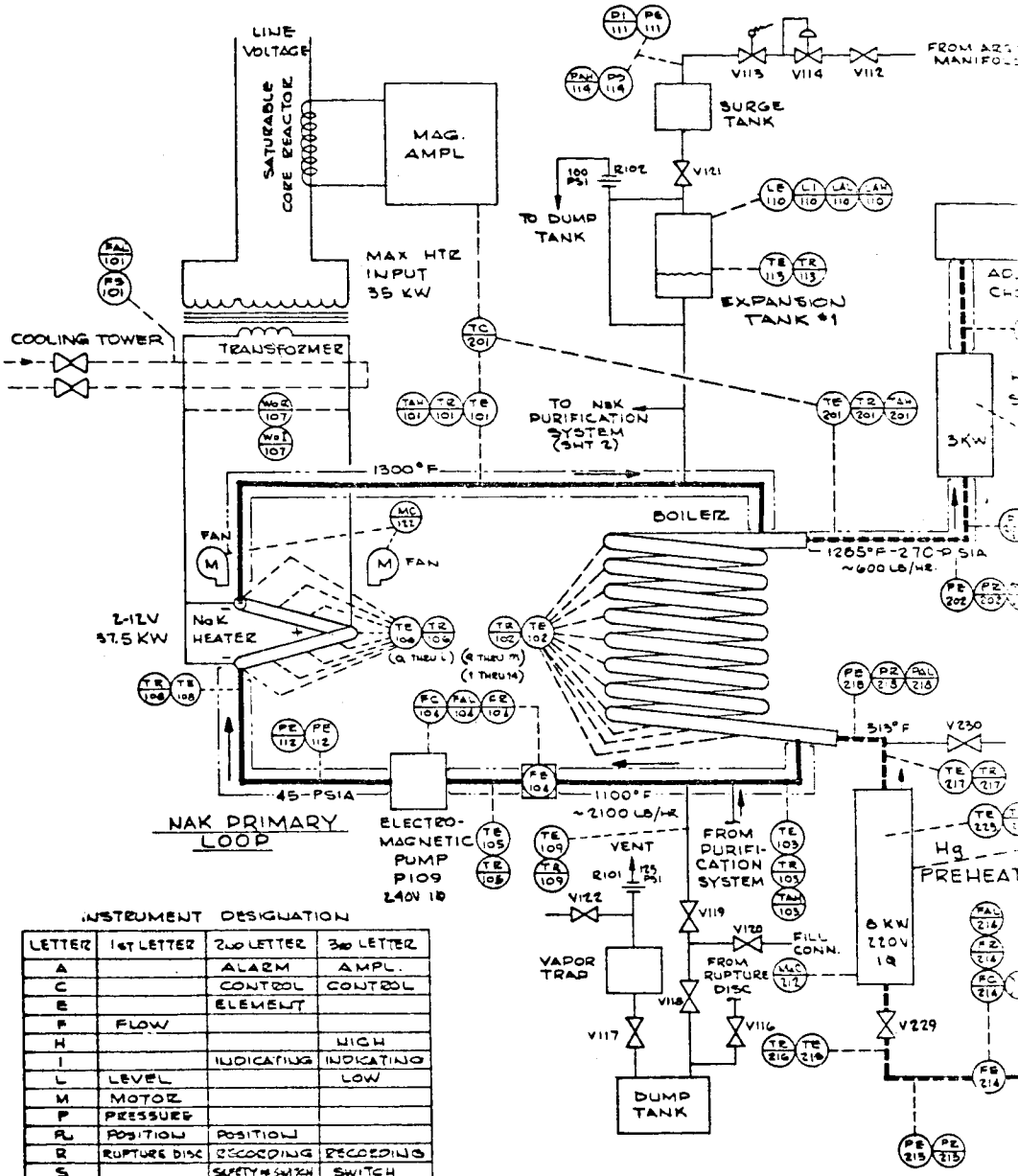
indicated on Motorola 4" scale strip chart recorders that have null balance potentiometer type movements. In addition, these pressures are also transmitted into a "Honeywell Visicorder" which is a mirror galvanometer ocillograph using "Instant Trace" paper. The Visicorder serves to check the small scale Motorola recorder as well as indicating the amplitude and frequency of the recorded pressure. Two 10" diameter 0-400 psig, 1/4% accuracy Heise gauges are also connected in parallel to the pressure taps of the instrumented plug.

The transducers are calibrated when a new plug insert is installed. Calibration of the transducers is accomplished by applying regulated nitrogen gas at the transducer pressure connection, this pressure is simultaneously monitored on a Bordon tube test gauge of traceable accuracy. Several pressure increments throughout the operating range are applied, and the indicator readings recorded. Correction curves are drawn from the results and used to correct subsequent test data. The initial accuracy of each pressure measuring system is found to be the resolution accuracy of the indicator and is within 1% of full scale.

4. Flow Measurement

An ASME standard venturi flow meter with the throat diameter of 0.100" is used for metering mercury flow. The differential pressure across the flowmeter is parallel to an electronic transducer and a pneumatic transmitter. The electrical output signal from the transducer is then amplified and indicated on a Motorola 4" strip chart recorder. The pneumatic transmitter output signal of 3-12 psig is transmitted directly to a 12" circular recorder indicator. Periodically, these recorder readouts are calibrated against known mercury flow rates which are within the test run operating range. The calibration flow rate is established by accumulating a given weight of mercury on a scale over a measured time increment. The maximum overall error in weight flow is ± 4%.

The NaK flow is measured by a permanent magnet flowmeter manufactured by MSA Research Corporation. The flowmeter dc output is amplified and indicated on a Motorola 4" strip chart recorder indicator. The recorder accuracy is approximately 1% full scale. The overall NaK weight flow accuracy is estimated as ± 2%.



INSTRUMENT DESIGNATION

LETTER	1st LETTER	2nd LETTER	3rd LETTER
A		ALARM	AMPL.
C		CONTROL	CONTROL
E		ELEMENT	
F	FLOW		
H			HIGH
I		INDICATING	INDICATING
L	LEVEL		LOW
M	MOTOR		
P	PRESSURE		
PL	POSITION	POSITION	
R	RUPTURE DISC	RECORDING	RECORDING
S		SAFETY OR SWITCH	SWITCH
T	TEMPERATURE	TRANSMITTER	
V	VALVE		
Wq	WATT (PWR)		
Mq	MANUAL		
X		PATCH PANEL	
Δ	DIFFERENTIAL		

SYMBOL LEGEND

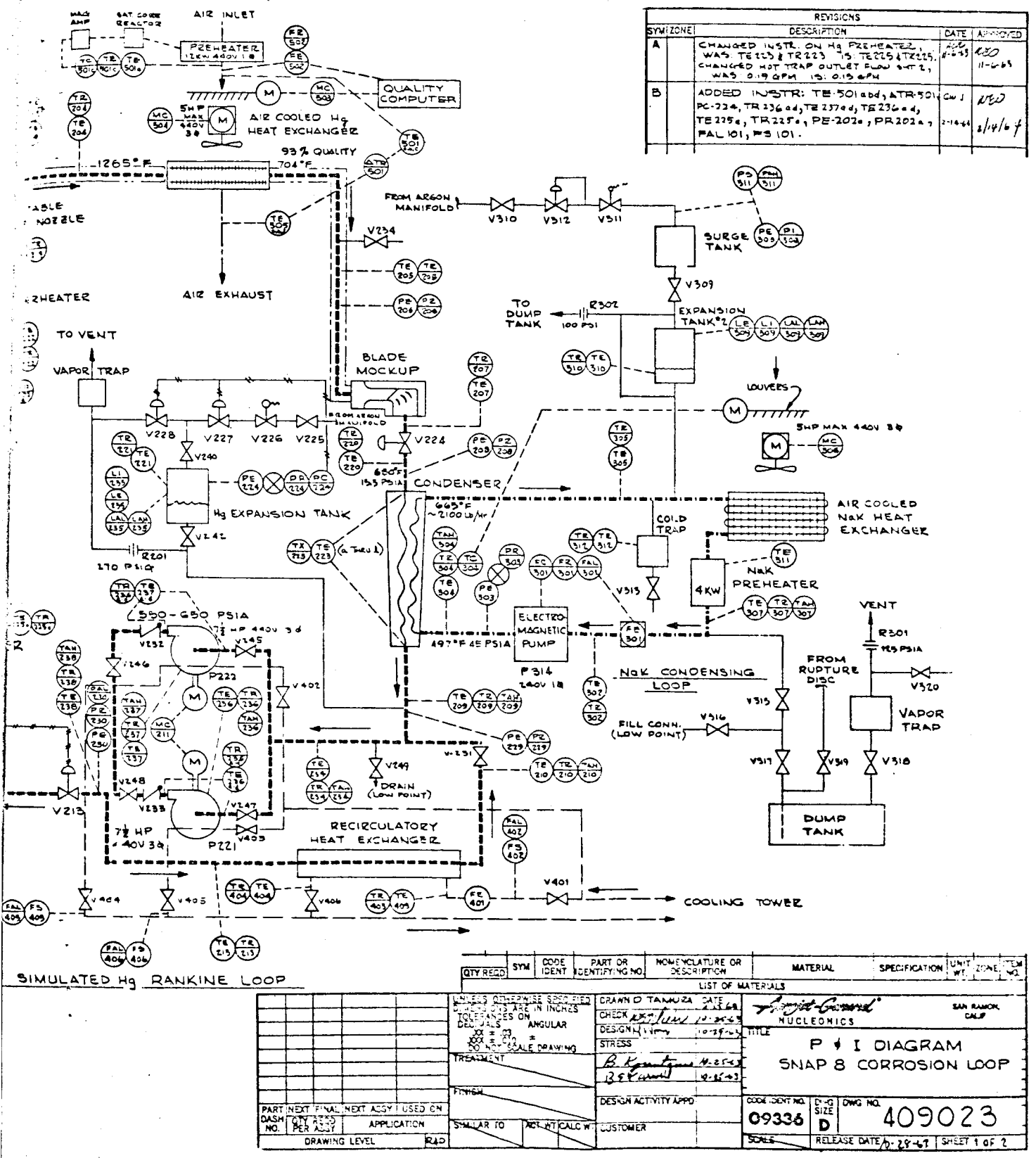
- TRANSMITTER
- LOCAL INSTRUMENT
- INSTR. DESIG. CONSOLE MTD. INSTRUMENT, INSTR. NO.
- RUPTURE DISC
- MANUAL VALVE
- CONTROL VALVE
- SOLENOID VALVE
- CHECK VALVE
- INSULATION

SYSTEM DESIGNATION

LINE	SYSTEM	NO. SERIES
	PRIMARY LOOP (NaK)	100 - 199
	SIMULATED Hg RANKINE LOOP	200 - 299
	NaK CONDENSING LOOP	300 - 399
	INSTR. LEAD	
	WATER LOOP	400 - 499
	INSTR AIR LINES	
	AIR DUCT	500 - 599
	NaK PURIFICATION	600 - 699

401-64-1327

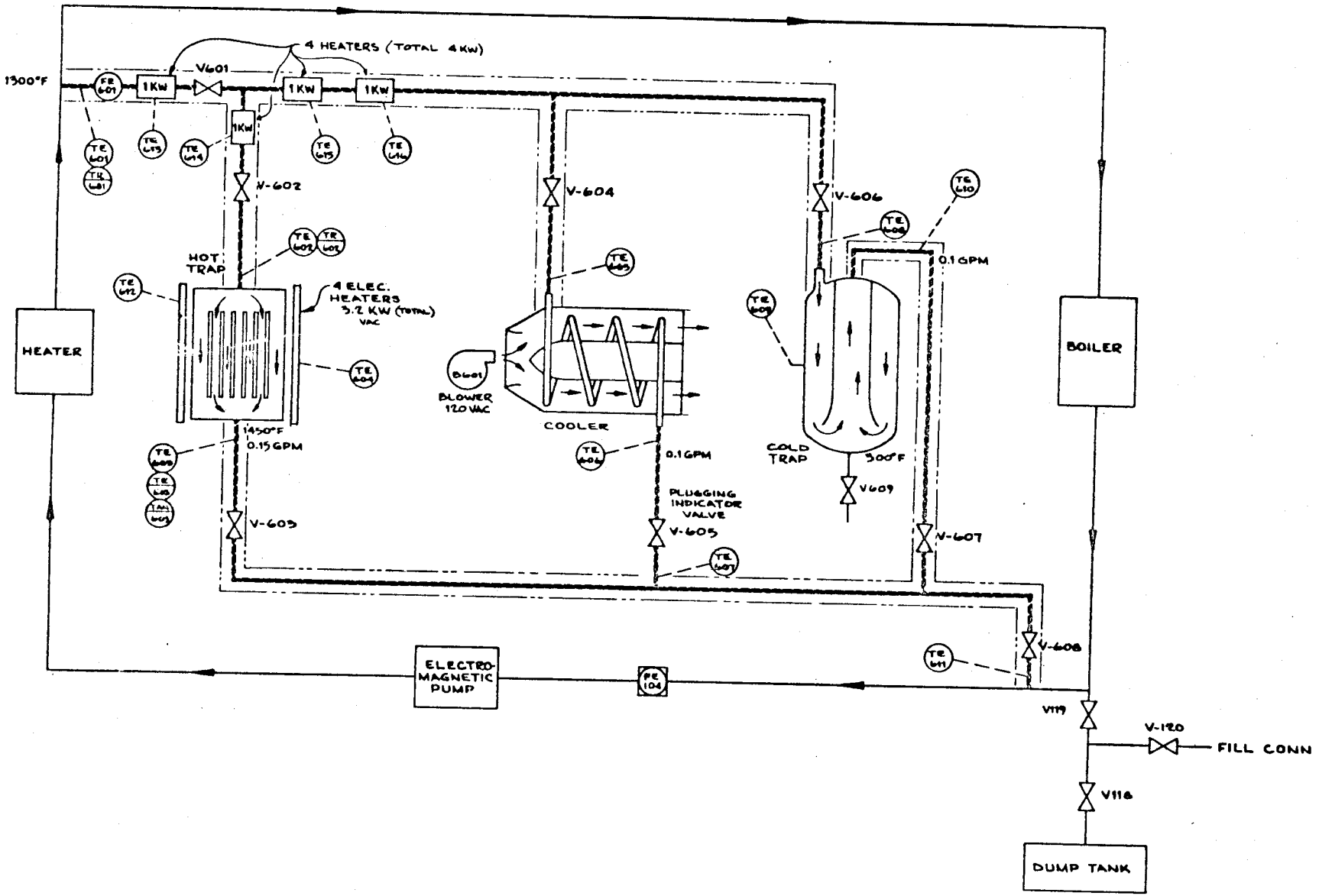
P



I DIAGRAM, SNAP-8 CORROSION LOOP

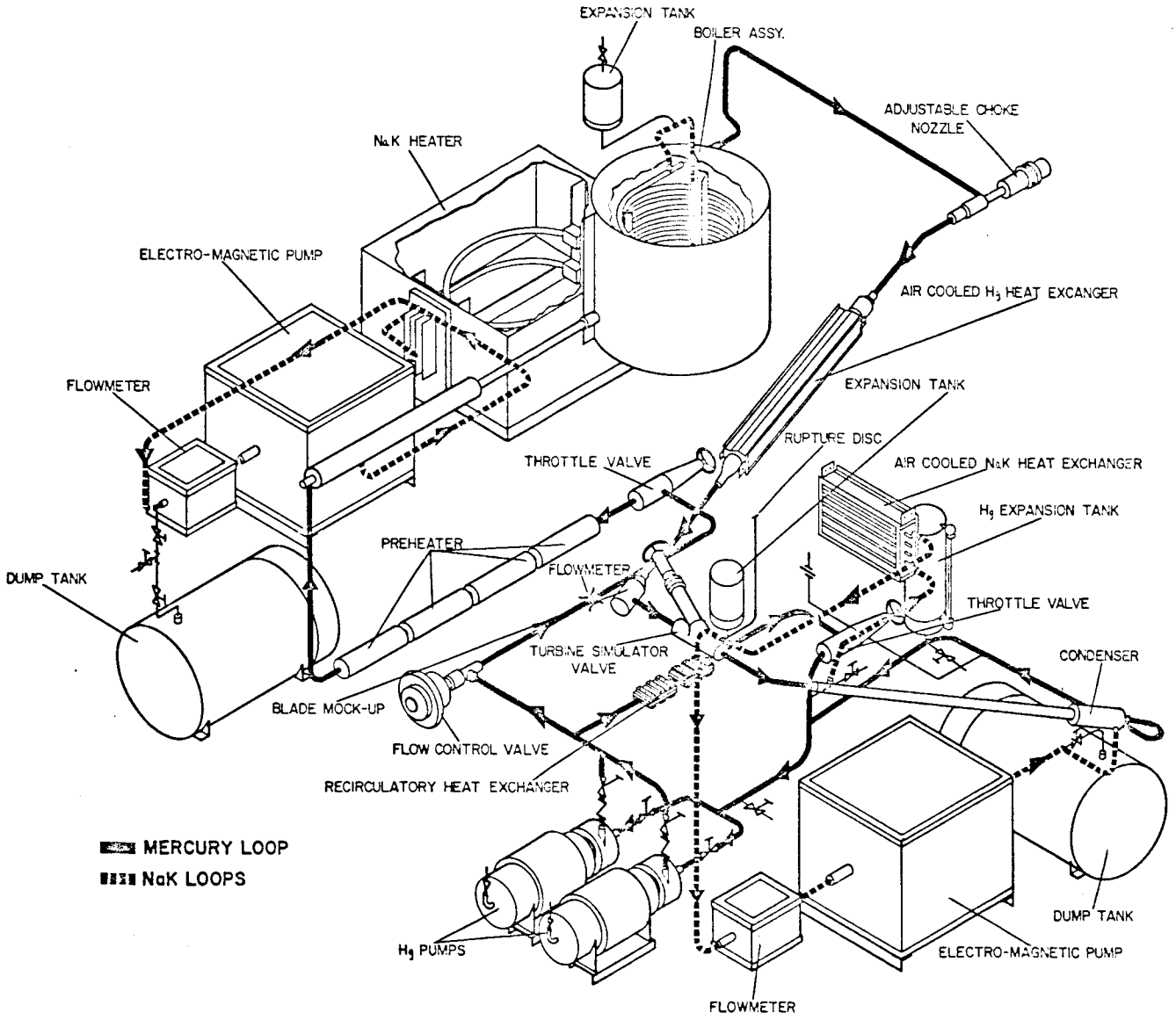
Fig. 3.1

40.1-64-1329



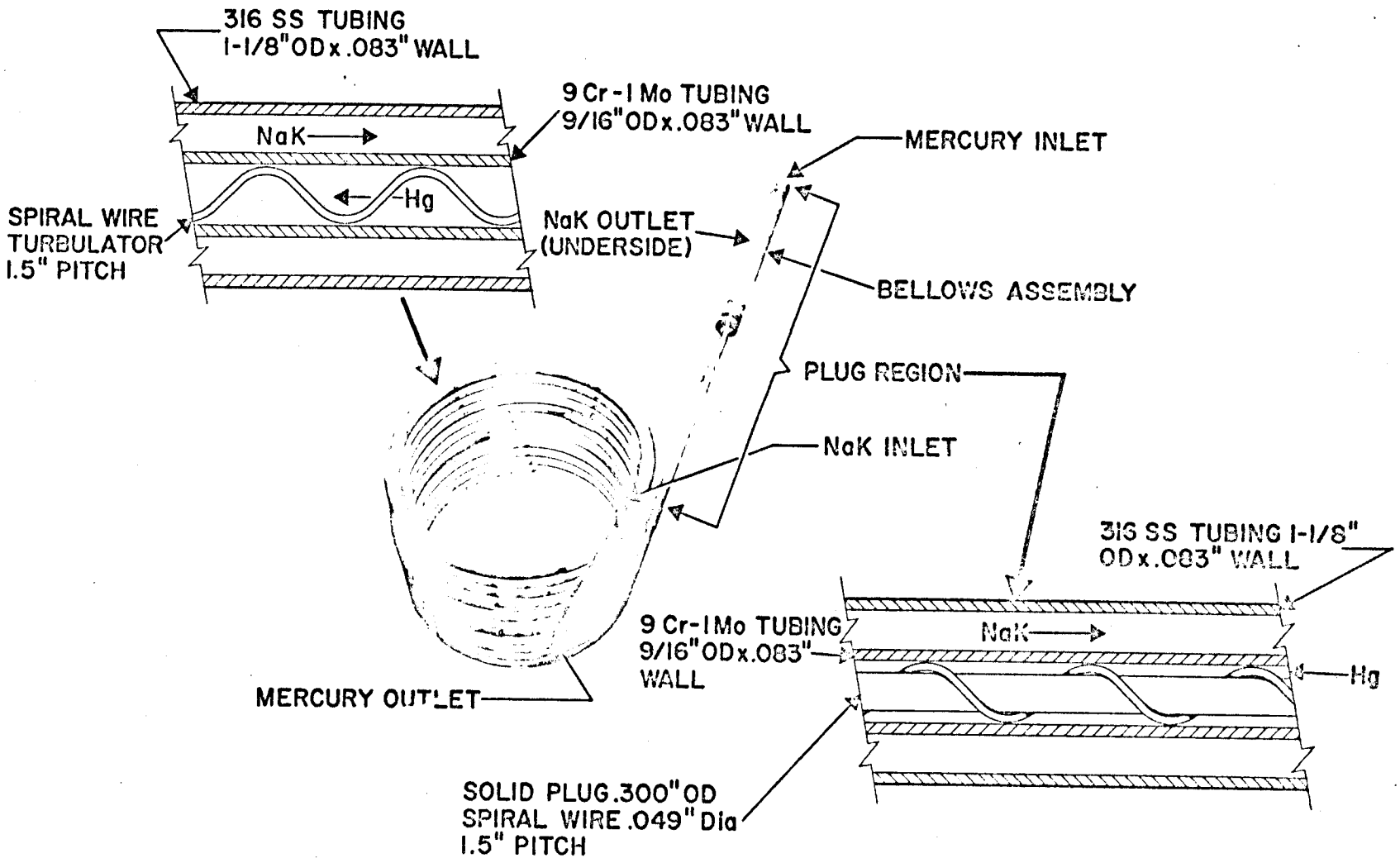
P & I DIAGRAM, NaK PURIFICATION SYSTEM FOR SNAP-8 CORROSION LOOP

Fig. 3.1a



CORROSION LOOP LAYOUT

Fig. 3.2



Mercury Boiler

Fig. 3.3

CL-4 BOILER (D X L = 0.400 IN. X 60 FT)

PLUG INSERT GEOMETRIES TESTED

TEST RUN NO.	PLUG INSERT NO.	L	PREHEAT SECTION					VAPOR SECTION				REMARKS
				W	h	P_1	L_1		P_2	L_2		
		IN.	TYPE[1]	IN.	IN.	IN.	IN.	TYPE[1]	IN.	IN.	INSTRUMENTED	
1	1	--	W	--	--	.75	21	W	.75	36	NO	POOR PERFORMANCE DURING FIRST 660 HR
2	2	6	W	--	--	.125	15	W	.75	36	NO	GOOD INITIAL PERFORMANCE
3	2	6	W	--	--	.125	15	W	.75	36	NO	GOOD RESTART PERFORMANCE
4	1	--	W	--	--	.75	21	W	.75	36	NO	GOOD RESTART PERFORMANCE
5	3	9	M	.033	.048	.125	15	W	.75	36	YES	GOOD PERFORMANCE D = .397" (ASSUMED)
6	4	9	M	.038	.045	.125	15	W	1.50	36	YES	GOOD PERFORMANCE D = .400" (ASSUMED)
7	4	9	M	.038	.045	.125	15	W	1.50	36	YES	GOOD PERFORMANCE PLUG #4 REINSERTED
8	3a	9	W	--	--	.125	15	W	1.50	36	YES	GOOD PERFORMANCE
9	3a	9	W	--	--	.125	15	W	1.50	36	YES	GOOD PERFORMANCE P_{ex} AND P_{in} OSCILLATION
10	3b	6	W	--	--	.17	15	W	1.50	24	YES	GOOD PERFORMANCE REDUCED P_{PL}

1 M = Machined Thread
W = Wire Wound

NOTES: a. All Wire Uses = 0.049 in. Diameter
b. OD of Plugs = 0.0398 in.

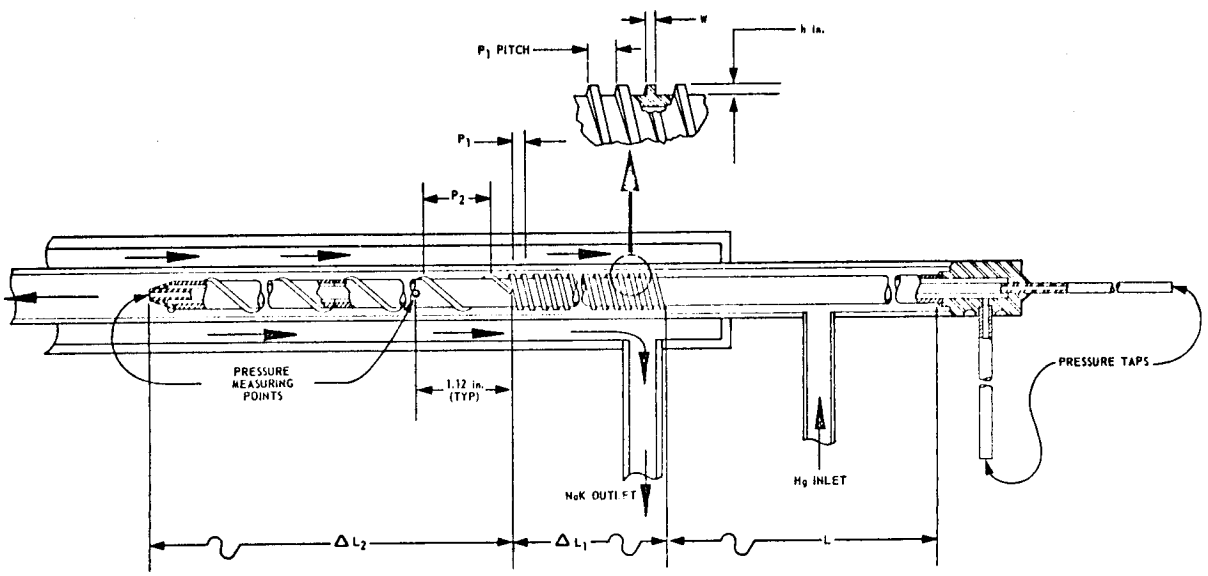
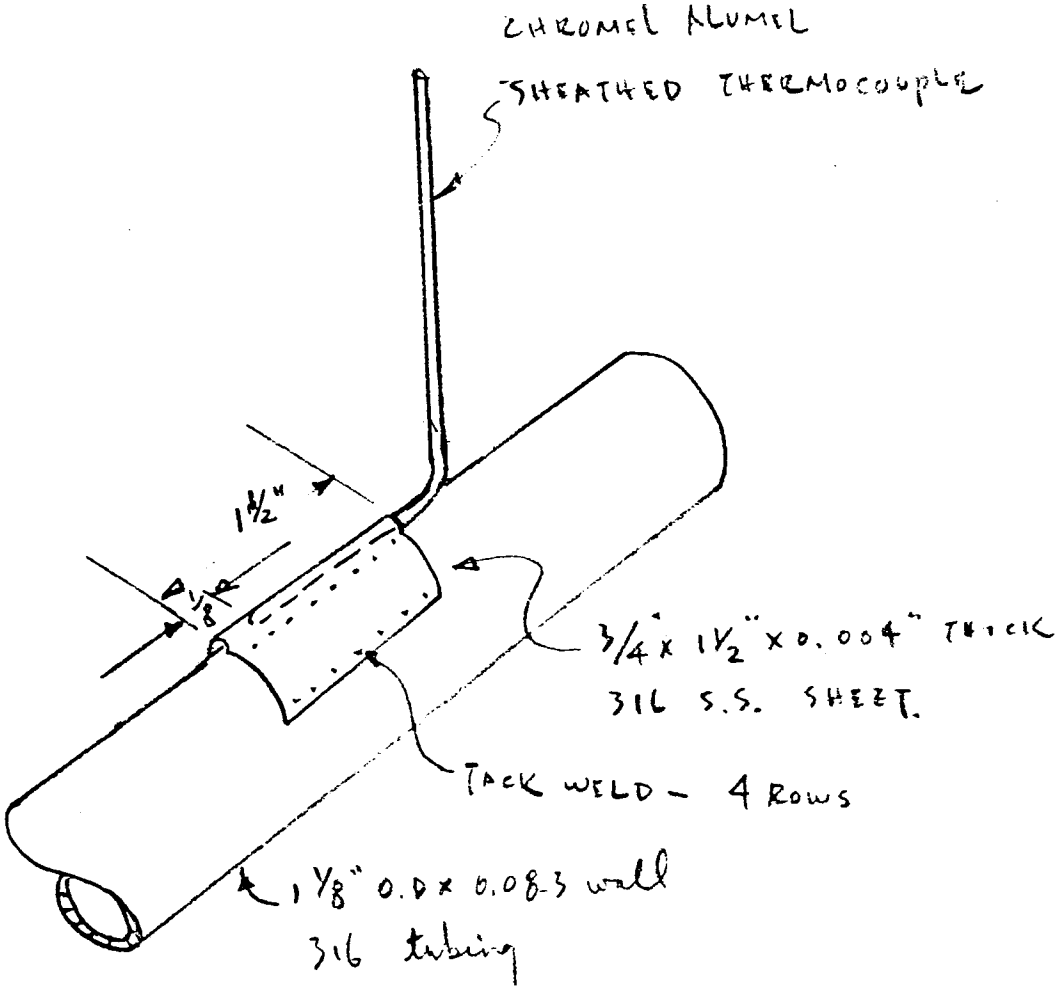
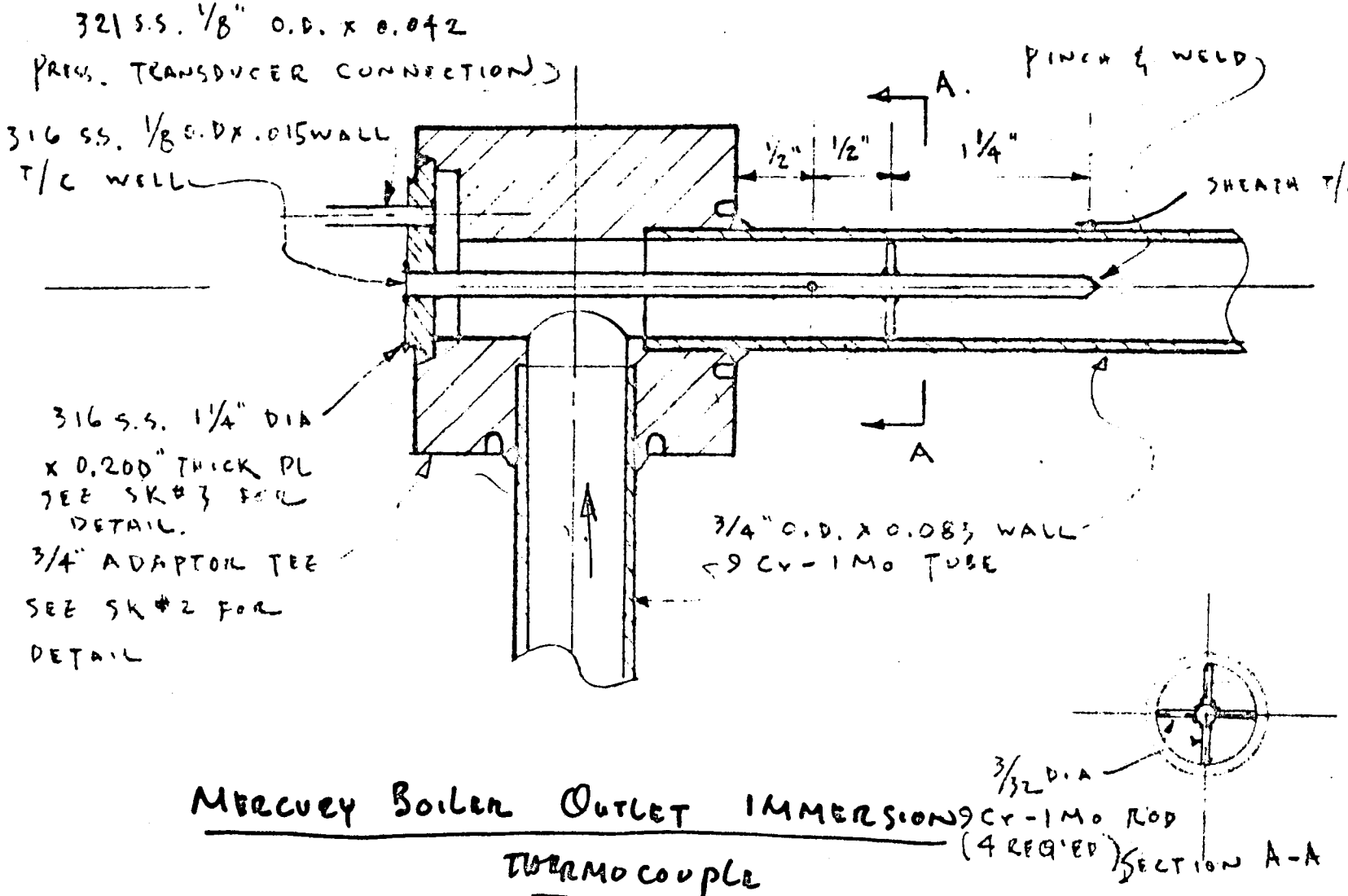


Fig. 3.4



THERMOCOUPLE INSTALLATION ON BOILER

Fig. 3.5



MERCUEY BOILER OUTLET IMMERSION THERMOCOUPLE

Fig. 3.6

IV. OPERATION*

The pretest preparation includes the instrumentation installation and calibration, mechanical checkout and calibration, and loading of three loops. This preparation is accomplished in accordance with Reference 5.

A. BOILER STARTUP

The temperature of the NaK in the primary loop is slowly raised up to 1150°F measured at the boiler inlet. Four hours is usually required to reach this temperature. During the heating up period, the primary NaK pump is started and flow is slowly increased to a maximum of 2050 lb/hr, and a vacuum of approximately 10-20 torr is maintained in the mercury loop to degas the mercury boiler. A dry ice in acetone trap between the mercury loop and vacuum pump collects any mercury or condensible vapors. Upon reaching the NaK temperature of 1150°F the mercury loop is sealed and the vacuum system is removed. The mercury pump is started initially into a bypass system and then injected into the boiler. The adjustable choke nozzle is in the fully open position during the hot start. An approximate mercury flow rate of 200-350 lb/hr is circulated through the boiler. When the flow is stable the NaK boiler inlet temperature is slowly increased to the test condition. The mercury system is allowed once more to stabilize. To obtain the desired pressure at the mercury boiler outlet, the adjustable choke nozzle is gradually closed. Normally, the time elapsed from mercury injection to the first test point is about two hours and during this period regular observations are made to monitor the boiler NaK shell temperature and other test parameters.

B. TEST RUNS

When a test program is designed, the order in which the test points are run is considered carefully since it is desired to have the least temperature disruption in the boiler. Once the test point conditions are acquired and the boiler temperature appears stable, it is standard practice to allow the NaK shell temperature profile to remain stable for at least thirty minutes before the data is taken. To further substantiate the data validity, several test points are repeated at the end of the test.

---

* Acknowledgement: The boiler plug insert performance tests were performed by E. McDaniel, B. Farwell, A. Herdt, J. Ralphs, G. Redfern and M. Wong.

C. SHUTDOWN

For a normal shutdown, the mercury flow into the boiler is first valved off and the primary NaK is allowed to circulate. Power to the heater is shutoff as soon as the mercury flow into the boiler is stopped. The NaK flow is continued until the boiler inlet temperature is cooled down to about 600°F by natural convection. After the boiler is cooled to room temperature, the vacuum system and cold trap system are connected to the mercury loop, and a vacuum of 15-20 torr is maintained until the next startup. If a prolonged shutdown or a plug insert change is scheduled, an argon cover gas of a slight positive pressure is applied and maintained on the mercury loop and boiler at all times.

V. TEST DATA REDUCTION

The test data reduction and analysis is based on the obtained NaK and liquid mercury flow measurements, the boiler NaK and mercury flow terminal temperature measurements, and the boiler NaK-shell-tube surface temperature profile in conjunction with mercury flow passage pressure measurements located at the boiler inlet and exit. Two additional pressure measurements in the mercury flow passage are obtained by means of internally located pressure taps in the plug insert section. One is located at the preheat section end point. The other is located at the plug insert vapor section end point. Test data recordings used for test data reduction are contained in Appendix C.

In view of the limited number of mercury flow passage pressure taps, the pressure gradients between P_{Hbi}-P_1, P_1-P_2, and P_2-P_{Hbo} are assumed to be linear. The pressure measurements P_{Hbi}, P_1, P_2 and P_{Hbo} were taken from the pressure taps located at the boiler inlet, preheat section end point, plug insert end point and the boiler exit, respectively. The NaK shell-tube outer surface temperature profile representation is assumed to be identical to the mercury flow passage internal wall temperature profile. This assumption is based on the obtained overall thermal resistance value across the heat flow pass as determined from the test and the analytically determined total resistance across the NaK film and the tube wall. The comparison of these resistances shows that:

$$\left(\frac{1}{U}\right)_{Test} < \left(\frac{r_m}{r_o}\frac{1}{h_N} + \frac{t}{k_w}\right)_{design}$$

which means that (q'') test $>$ (q'') design. Obviously, the available data on tube wall thermal conductivity and the NaK side file heat transfer coefficient determination method is in error. This consideration implies that the NaK side film heat transfer coefficient is infinite, and the mercury tube wall heat transfer resistance is negligible.

Linear correction of the measured NaK temperature profile was introduced in the excess boiler superheat length. This correction was established from the heat balance analysis where the net NaK flow and the NaK temperature drop due to the external boiler heat loss were determined. For the average NaK flow rate used

in these tests the NaK temperature drop due to external heat loss was approximately 30°F. The boiler NaK shell-tube skin thermocouple temperature measurements at their best are estimated to be of ± 2.5% accuracy with respect to total full-scal indication.

Test data reduction and analytical computations were conducted on the IBM-7094 Model 2 computer. A detailed analytical program for this purpose is contained in Appendix B. The results are presented in tabulated form in Appendix A.

The main items determined for each test point data set were:

1. Boiler heat balance
2. Plug insert preheat section geometric, dynamic, and thermal parameters
3. Plug insert vapor quality section geometric and dynamic parameters
4. Plug insert section exit vapor quality
5. NaK temperature at liquid-vapor interface
6. NaK temperature in terms of vapor quality
7. Plug insert vapor quality section local boiling thermal and dynamic parameters
8. Unplugged tube vapor quality section local boiling thermal and dynamic parameters
9. Plug insert vapor quality section mean thermal parameters
10. Unplugged tube vapor quality section mean thermal parameters

VI. DISCUSSION OF RESULTS

The results of the test data reduction are evaluated in the light of proposed drop-wise drywall boiling heat transfer and two-phase flow pressure drop correlations. These correlations are based on mercury nonwetting characteristics which are the principal cause for the dropwise two-phase flow regime in the boiling section. To obtain the predicted boiler performance characteristics in accordance with this design approach, the experimental evidence indicates that the initial physical and/or chemical cleanliness of the wall surface in the mercury flow passage prior to mercury injection is of particular importance. Aside from the thermal and dynamic conditions at the liquid-vapor interface and in the vapor flow quality region, which are necessary to promote effective mercury vaporization, the obtained boiling heat transfer characteristics as represented by the NaK temperature profile, can be better or worse than those predicted by the dropwise drywall boiling theory. The boiler performing in accordance to these design expectations is said to be in a conditioned state. The boiler exhibiting better heat transfer characteristics is said to be in a partially-wetted state; the boiler exhibiting poorer heat transfer characteristics is said to be in a deconditioned state. When intermittent physical wetting on the mercury flow passage walls occurs, the boiler is said to be in a partially-wetted state. Partial wetting was observed on the plug insert surface when the plug insert was removed from our test boiler after 96 hours of operation. A typical NaK temperature profile for a deconditioned boiler is depicted in Appendix C, Figure C-1. The same boiler exhibiting fully-conditioned, or partially-wetted boiler heat transfer characteristics is shown in Figure C-4. The reason for obtaining the boiler NaK temperature profile as shown in Figure C-4 can be attributed to significant changes occurring on the mercury flow passage wall surface. The physical and/or chemical changes occurring on the material surface are only poorly understood, and require further investigation.

Initial test results as depicted in Appendix C, Figures C-1 through C-7, are of a qualitative nature. They show the effect of the liquid-phase velocity in the boiler preheat section on the overall boiler performance. Figures C-1 and C-2 depict a typical NaK temperature profile for a deconditioned boiler during the initial test run when the liquid-phase velocity in the helical flow passage was

0.8 ft/sec. Nonmeasurable improvement in the boiler conditioning effect was observed during several hundreds of hours of operation under a nominal SNAP-8 boiler NaK inlet temperature schedule. The same boiler, when restarted with a revised preheat section plug insert geometry providing a liquid-phase velocity of 6 to 7 ft/sec, exhibited effective mercury flow passage conditioning immediately. Also, the projected NaK temperature profile approached the design conditions very rapidly. Figures C-3 and C-4 show the progress in conditioning 4 hours and 20 hours after mercury injection, respectively. The boiler restart, (Figure C-5) with the same plug insert geometry, did not indicate any boiler performance degradation. A subsequent test run (Figure C-6), with the original preheat section plug insert, providing 0.8 ft/sec liquid-mercury velocity, still produced conditioned boiler performance characteristics. This evidence shows that once the tube surface is in a conditioned or wetted state, the liquid-velocity level in the preheat section is not of particular importance. Examination of the NaK temperature profiles (Figures C-6 and C-5) and associated test data reveals that the difference between the two plug insert geometries tested can be detected in the slope of the NaK temperature profile and in the boiling termination point. A tight liquid phase plug insert geometry combined with a similar low vapor quality region seems to be the right design approach for a high performance "once through" type boiler. Once the fully conditioned or even wetted mercury flow passage state is established, the boiler can also be operated without a plug insert. This condition is shown in Figure C-7, where the slope of the NaK temperature profile reflects boiling heat transfer rates comparable to those obtained with plug inserts. However, in the unplugged boiler this heat transfer is accompanied by excessive oscillations in boiler exit pressure and flow. It is postulated that nucleation sites were developed in the mercury flow passage plug insert regions during previous boiler test runs, when the elevated velocity plug insert geometries were tested. Thus, the boiler inlet and tube section, without a plug insert, was operating under a convective nucleate boiling heat transfer regime.

Test data point sets as shown in Appendix C, Figures C-8 through C-36, are representative of the obtained NaK temperature profiles and the associated primary and secondary working fluid operating parameters utilized in the test data reduction program. The results of this reduction are presented in tabulated form in Appendix A.

The calculated heat loss values as obtained from the heat balance closure are in the range from 1 to 16% of the total heat input. This discrepancy can be attributed to inaccuracies in temperature measurements or their corrections; e.g., the boiler NaK temperature drop error of $\pm$ 10°F results in a heat loss error of $\pm$ 1.26 kw. The boiler heat loss was also determined on the basis of boiler operation at zero mercury flow and different NaK flow and temperature levels. The estimated heat loss value is 2 to 2.5 kw or 9 to 10% of the total heat input.

Similar parametric data point scatter resulted from the boiler thermal and dynamic test data analysis, which can also be attributed to the inaccuracy of the boiler instrumentation. The most critical areas in this regard are the establishment of the true mercury temperature and pressure conditions in the boiler plug insert section. The point of particular interest is the determination of the liquid-vapor interface location in the boiler. To perform a detailed test analysis in this area, a much more sophisticated instrumentation technique is necessary. A typical and desirable boiler test data representation in conjunction with such an instrumentation is depicted in Figure 6.0-1. This representation implies that several mercury flow passage temperature measurements in the preheat (T_{PH}) and low quality vapor section (T_S, T_v) as well as the exact mercury flow pressure (P_{Hg}) and NaK flow temperature (T_N) profiles must be experimentally established. In accordance to this diagram, the liquid-vapor interface location (L_{OO}) is determined when T_{SOO}, T_{NOO} and P_{OO} are projected as the point L_{OO} on the abscissa. Our experimental boiler instrumentation is not providing this type of test data representation. Because of these limitations, the test data evaluation was performed on the basis of several assumptions in conjunction with trial and error methods wherever the available test data were not sufficient to support the analysis.

These assumptions are in the form of corrections in the curvature of the NaK temperature profile and the mercury pressure profile. They are further based on plug insert liquid and low vapor quality section calibrations. These calibrations provided pressure drop data, which were utilized to determine the liquid and gas flow frictional pressure drop factors for the different plug insert geometries tested. In making these calibrations, liquid and vapor flow rates were regulated so as to maintain the same Reynold's number range as that existing in the boiler when operating under normal conditions. The results of liquid flow calibrations are shown in Table 6.0-1.

The Darcy type pressure drop correlation for two-phase turbulent flow was used to determine the product ϕf_v, where

$$\phi = \frac{\Delta P_{TP}}{f_v \frac{De}{\Delta L'} \frac{(\bar{x} G)^2}{2 g_c \rho_v}} = \frac{\Delta P_{TP}}{\Delta P_v}$$

The product ϕf_v is correlated in terms of the Martinelli-type parameter

$$\lambda = \left(\frac{\bar{x} G De}{\mu_v}\right)^{.8} \frac{\mu_v}{\mu_f} \frac{\rho_f}{\rho_v} \frac{\bar{x}}{1-\bar{x}}$$

which is determined from an incremental local boiling heat transfer analysis. ϕf_v versus λ is plotted separately for plug insert section and unplugged tube section geometries. Figure 6.0-2 shows the low vapor quality (up to 15%) pressure drop correlating parameters, when the vapor quality region next to the liquid-vapor interface enters the plug insert preheat section. Figure 6.0-3 shows the same correlating parameters for the plug insert vapor quality range from 0 to 80%. The data in Figure 6.0-3 were fitted by least squares analysis providing the average curve

$$\phi f_v = e^{4.87} \lambda^{-.674}$$

The average two-phase flow pressure drop factor is determined from the above curve using

$$\phi = \frac{\phi f_v}{f_v}$$

where f_v is obtained from N_2 gas flow tests carried out in a Reynold's number range corresponding to 100% vapor flow. Figure 6.0-4 shows a similar plot of data points in the unplugged tube section for the vapor quality range from 20 to 100%. A least squares analysis of the data predicted a curve for best fit given by

$$\ell n \, \phi f_v = 16.06 - 2.224 \, \ell n \, \lambda + .065 \, (\ell n \, \lambda)^2 .$$

The comparison of two plug insert geometries in regard to their pressure drop in terms of plug insert end point vapor quality is illustrated in Figure 6.0-5. Curve 2 as compared to Curve 1 shows that excessive boiler pressure drop may result when the plug insert length is overdesigned. In the case of oversized preheat

section plug insert length and tight pitch helical flow passage geometry, early vapor generation may occur in the preheat section. Under these conditions the total plug insert pressure drop may reach undesirable proportions (Curve 3 and 4).

The magnitude of the obtained initial boiling heat fluxes in terms of the temperature difference at the liquid-vapor interface location is plotted in Figure 6.0-6. In view of the wide scatter of the test data the points can be approximated in the form $q'' = \text{const.}\ \Delta T_{00}$, which is a linear function with a 45° slope. This interpretation would indicate that convection vortex type boiling was induced from the liquid-vapor interface location by the elevated liquid phase velocity.

The vapor quality section thermal and dynamic operating parameters in dimensional and non-dimensional form were determined on the basis of local boiling heat transfer and two-phase flow pressure drop correlations in 20% vapor quality increments. To check out and compare these results with the dropwise dry wall boiling theory the obtained local boiling mean temperature difference (ΔT_M) of each quality increment was considered in the light of boiling heat transfer design correlations for the purpose of determining whether it was in the contact, intermittent contact, or film boiling regime. These results, as well as the results of the analysis of the overall heat transfer in the plug insert section and the unplugged tube vapor section, are tabulated in Appendix A.

For each vapor quality increment ($\Delta x = .20$) throughout the length of the boiling section the calculated mean heat fluxes are plotted in terms of the mean temperature difference between the NaK temperature and the mercury saturation temperature. The mean NaK temperature of each quality increment is determined from the boiler NaK temperature profile. The mercury saturation temperature is determined from the mercury flow passage pressure representation in the same quality increment. Plots of the obtained local boiling heat fluxes at mean vapor qualities of 10, 30, 50, 70 and 90% in terms of mean temperature differences are shown in Figures 6.0-7 thru 6.0-11, respectively. The data scatter display was analyzed by least squares techniques to obtain curves of best fit. The results of this analysis are shown graphically as well as analytically in the figures indicated above.

The results of local boiling heat transfer representation as discussed above are further differentiated into boiling occurring in the plug insert section

and boiling occurring in the unplugged tube section. The data points of each quality increment of these sections were considered in the light of different boiling regimes as defined by the dry wall dropwise boiling correlations. These correlations are:(1)

Contact boiling:

$$Nu_C = \frac{1}{32}\ Nu_\delta^2 \left(\frac{k_f}{k_v}\right)^2 \left(\frac{D}{\delta_o}\right)^2 \left(\frac{\rho_v}{\rho_f}\right) \frac{(1-x)^{1/3}}{x}$$

Intermittent contact boiling

$$Nu_{IC} = 234\ C^4 \left(\frac{k_v}{k_f}\right)^4 \left(\frac{\delta_o}{D}\right) \left(\tan\alpha \frac{DG}{\mu_v} \frac{h_{fv}\ \mu_v}{k_v\ \Delta T_M}\right)^2 (1-x)^{4/3}\ x$$

Film boiling

$$Nu_F = \frac{6^{1/3}}{4} \left(\frac{D}{\delta_o}\right) \left(\frac{4/3}{9}\right) \left(\frac{DG}{\mu_v} \tan\alpha \frac{\rho_v}{\rho_f} \frac{h_{fv}\ \mu_v}{k_v\ \Delta T_M}\right)^{2/3} \frac{(1-x)^{2/3}}{x^{1/3}}$$

The boiling regimes are determined by equating $Nu_C = Nu_{IC}$ and $Nu_{IC} = Nu_F$ and solving then for $\Delta T_M = \Delta T_{cr}$ accordingly. These solutions are:

$$\Delta T_{cr-1} = \frac{h_{fv}\ \mu_v\ C^2\ (7488)^{\frac{1}{2}}\ \left(\frac{k_v}{k_f}\right)^3\ \left(\frac{DG}{\mu_v}\right)\ \tan\alpha\ (1-x)^{\frac{1}{2}}\ x}{k_v\ \left(\frac{D}{\delta_o}\right)^{3/2}\ \left(\frac{\rho_v}{\rho_f}\right)^{\frac{1}{2}}}$$

If $\Delta T_{cr-1} > \Delta T_M \longrightarrow$ use contact boiling regime.

If $\Delta T_{cr-1} < \Delta T_M \longrightarrow$ calculate ΔT_{cr-2}

$$\Delta T_{cr-2} = C^3 \left(\frac{h_{fv}\ \mu_v}{k_v}\right) \frac{936^{3/4} \left(\frac{k_v}{k_f}\right)^3 \left(\frac{DG}{\mu_v}\right) (\tan\alpha)\ (1-x)^{1/2}\ x}{6^{1/4}\ \left(\frac{D}{\delta_o}\right)^{3/2}\ \left(\frac{\rho_v}{\rho_f}\right)^{1/2}\ g}$$

If $\Delta T_{cr-2} > \Delta T_M \longrightarrow$ use intermittent contact boiling regime

If $\Delta T_{cr-2} < \Delta T_M \longrightarrow$ use film boiling regime.

The empirical constants taken from Reference 1 are:

	e	C	Nu_δ
$0 < x < .4$	.43	2.3	-
$.4 < x < 1.0$	1.00	3.0	-
$0 < x < 1.0$	-	-	.8

These values were used to plot the design curves (q" vs. ΔT_M) superimposed on the test data plots. The results of these considerations are depicted in Figures 6.0-12 thru 6.0-19.

Figure 6.0-12 shows the test results in relation to the design expectations. The curves $Nu_\delta = .54$ and $C = 2.0$ are derived from the test data and suggest a more conservative design approach in this plug insert mean quality increment.

Figure 6.0-13 shows similar comparison of expected and obtained boiling heat fluxes at $\bar{x} = .30$ in the plug insert section. The design curves $Nu_\delta = .8$ and $C = 2.3$ are in good agreement with the test results.

Figure 6.0-14 shows the heat fluxes obtained at $\bar{x} = .30$ in the unplugged tube section. The design curve $C = 2.3$ as well as the curve derived from test data are in close agreement.

Figure 6.0-15 shows the test data at $\bar{x} = .50$ in the plug insert section. The design curve $Nu_\delta = 1.26$ derived from the test data is considerably higher than the one used for the design prediction. This may be attributed to the dynamic two-phase flow conditions existing in this mean quality section of the plug insert. The vapor flow helical velocity at $\bar{x} = .50$ is in excess of 100 ft/sec. Considerable radial acceleration g forces could, therefore, be induced on the liquid droplets carried by the vapor. Consequently the contact area of droplets at the tube wall is increased because of droplet deformation or break-up.

Figure 6.0-16 depicts the test results at $\bar{x} = .50$ in the unplugged tube section. The design prediction curve $C = 3.0$ and the average curve $C = 3.1$, as derived from the test data, are, however, in close agreement.

Figure 6.0-17 shows test results at $\bar{x} = .70$ in the plug insert region. It refers to results similar to those shown in Figure 6.0-15. Both cases are accompanied by relatively high pressure drops through the plug insert vapor quality region.

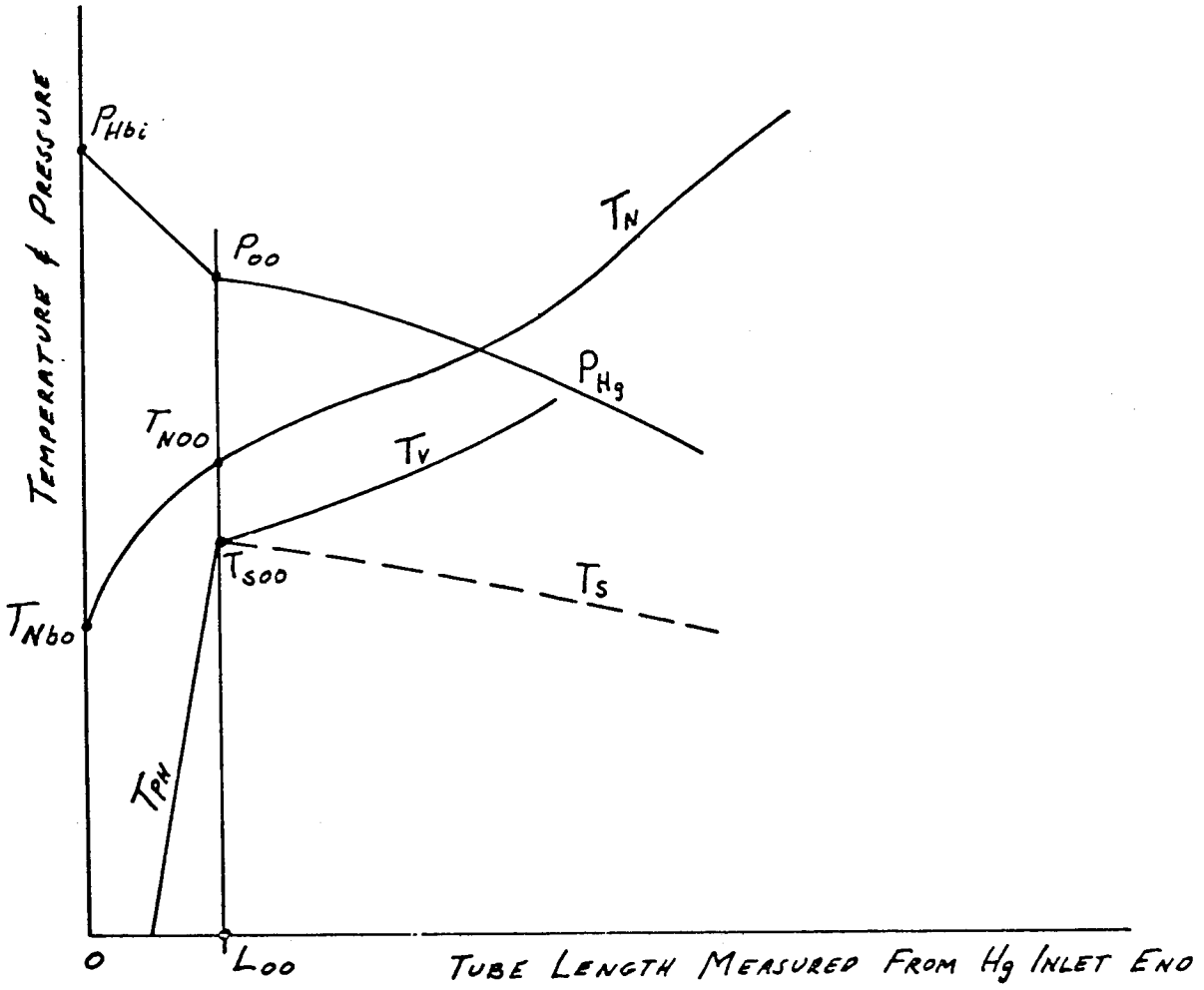
Figure 6.0-18 provides the results at $\bar{x} = .70$ in the unplugged tube section. These heat transfer data can be represented by a local intermittent contact boiling regime at $C = 3.6$. The design prediction using $C = 3.0$ is still a good conservative design approach.

Figure 6.0-19 shows that test data at $\bar{x} = .90$ fall below the expectation of the film boiling regime. This can be explained by test data inaccuracy and error introduced by the estimation of the boiler length at the 100% vapor quality point.

Typical boiling heat flux representations at SNAP-8 operating conditions are shown in Figure 6.0-20. These curves indicate that heat transfer effectiveness and thus the boiler vapor quality section length is dependent on boiler NaK inlet temperature (T_{Nbi}) and the NaK temperature drop (ΔT_N) thru the boiler. The minimum boiling length occurs under a high boiler NaK temperature schedule, which is shown by curve A. The maximum boiling length, as shown by the available heat fluxes of curve B, occurs under a low NaK temperature schedule.

CL-4 BOILER TEST PLUG INSERT FLOW PAS E CALIBRATION RESULTS TABLE 6.0-1

PLUG INSERT NUMBER	A_c	De	$\Delta L'$	G		μ	ρ	u	W	ΔP	T	Re	f
	ft^2	ft	ft	~~lbm/sec-ft²~~	lbm/hr-ft^2	lbm/hr-ft	lbm/ft^3	ft/sec	lbm/hr	psi	°F		
3 (Run #5)	3.05×10^{-5}	5.24×10^{-3}	12.65	3640	1.31×10^7	2.65	824	4.42	400	27	300	25,900	.00648
	"	"	"	4550	1.64×10^7	"	"	5.53	500	34.8	"	32,600	.00533
	"	"	"	5470	1.98×10^7	"	"	6.63	600	50.3	"	39,000	.00531
5 (Run #6)	2.71×10^{-5}	4.95×10^{-3}	12.81	4110	1.48×10^7	2.71	826	4.97	400	81	280	27,000	.01424
	"	"	"	5130	1.85×10^7	"	"	6.23	500	114	"	33,800	.01281
	"	"	"	6150	2.21×10^7	"	"	7.45	600	156.5	"	40,400	.01223
	"	"	"	7200	2.58×10^7	"	"	8.71	700	205.5	"	47,200	.01172
5 (Run #7)	"	"	"	4110	1.48×10^7	2.81	829	4.96	400	71	250	26,200	.0125
	"	"	"	5130	1.85×10^7	"	"	6.21	500	99	"	32,700	.0110
	"	"	"	6150	2.21×10^7	"	"	7.42	600	128	"	39,200	.0100
6 (Run #8)				4360	1.57×10^7	2.64	824		400	62	300	29,200	.0097
				5450	1.96×10^7	"	"		500	68	"	36,400	.0068
				6530	2.35×10^7	"	"		600	104	"	43,700	.0073
7 (Run #10)				2950	1.16×10^7	2.68	825		450	30	290	24,900	.0163
				3430	1.24×10^7	"	"		500	35.5	"	26,500	.0143
				3780	1.36×10^7	"	"		550	41	"	29,200	.0136
				4120	1.48×10^7	"	"		600	47	"	31,800	.0131
				4470	1.61×10^7	"	"		650	52.5	"	34,400	.0125
3 (Run #5)						1.87	783		400	28.4	800	36,700	
						"	"		500	36.6	"	46,200	
						"	"		600	52.9	"	55,300	
5 (Run #6)						"	"		400	85.5	"	39,100	
						"	"		500	120.2	"	49,000	
						"	"		600	165	"	58,600	
						"	"		700	217	"	68,300	
5 (Run #7)						"	"		400	75.2	"	39,400	
						"	"		500	105	"	49,200	
						"	"		600	135.4	"	58,900	
6 (Run #8)						"	"		400	65.3	"	41,500	
						"	"		500	71.5	"	51,600	
						"	"		600	109.4	"	61,900	
7 (Run #10)						"	"		450	31.6	"	35,700	
						"	"		500	37.4	"	38,000	
						"	"		550	43.2	"	41,800	
						"	"		600	49.5	"	45,600	
						"	"		650	55.3	"	49,300	



TYPICAL BOILER TEMPERATURE AND PRESSURE PROFILES AT MERCURY INLET END

FIG. 6.Q-1

CL-4 BOILER TEST
TWO PHASE FLOW PRESSURE DROP CORRELATING PARAMETERS
IN PLUG INSERT PREHEAT SECTION

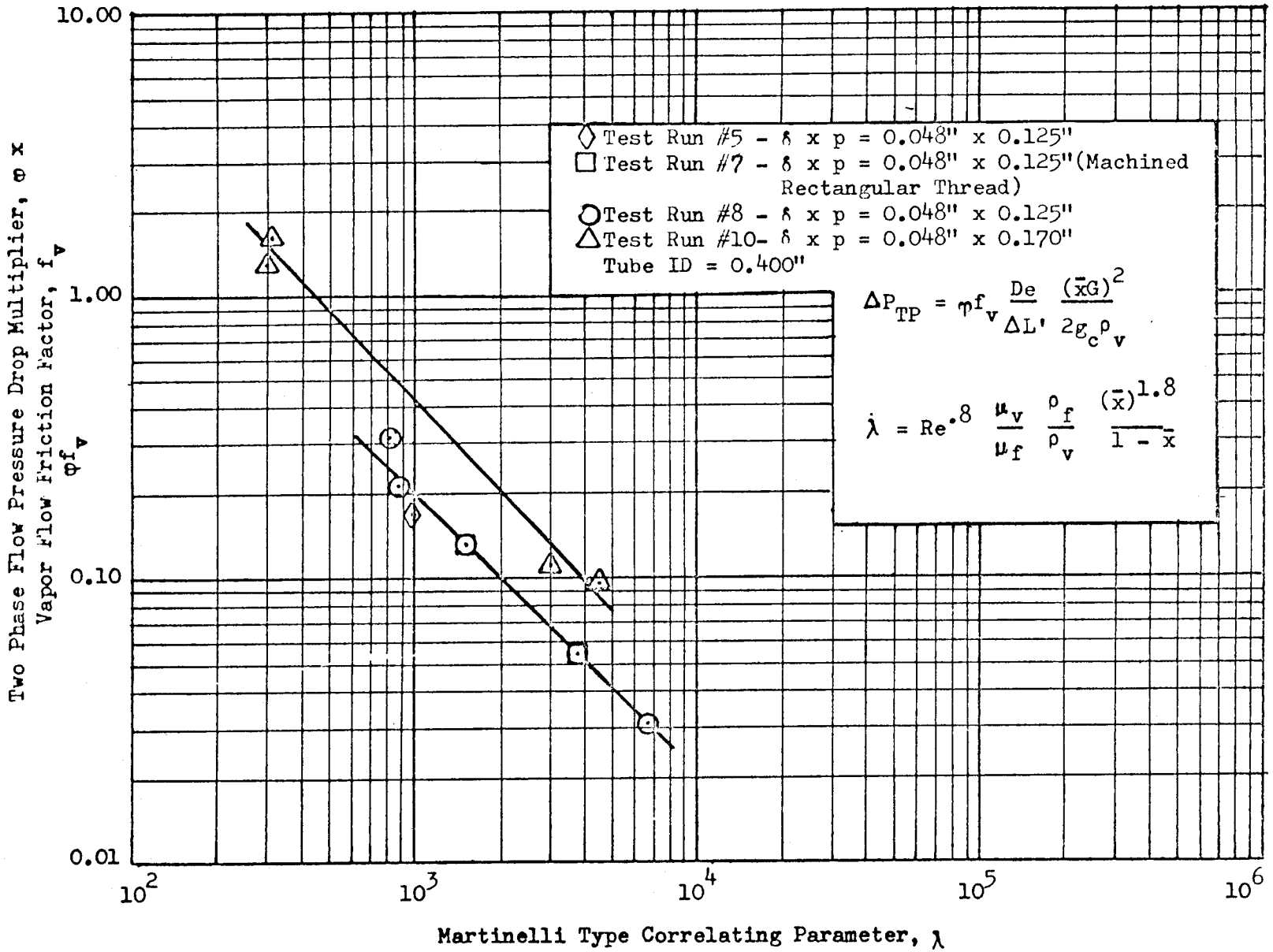


Figure 6.0-2

CL-4 BOILER TEST
PLUG INSERT TWO PHASE FLOW PRESSURE DROP
CORRELATING PARAMETERS

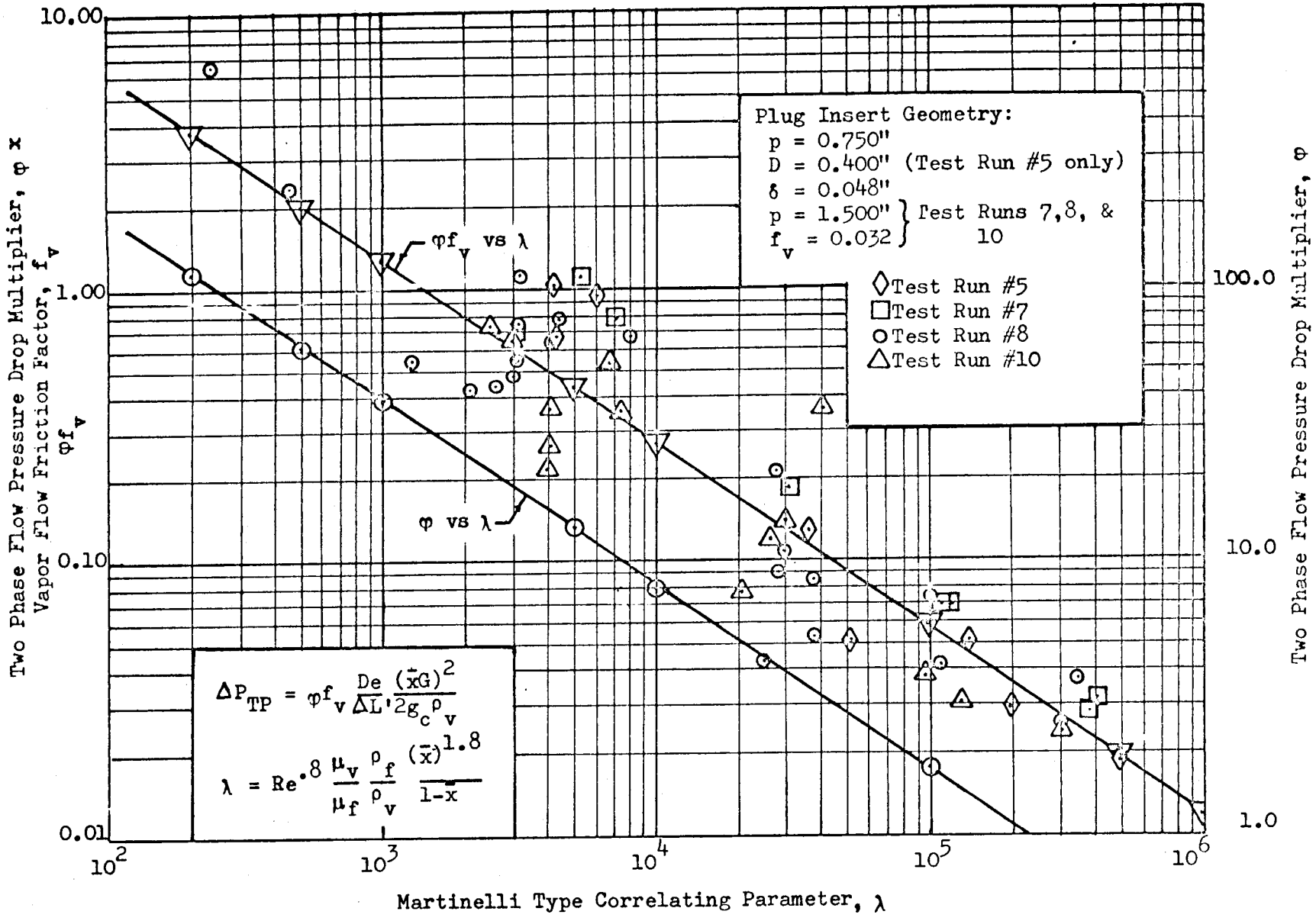


Figure 6.0-3

CL-4 BOILER TEST
UNPLUGGED TUBE TWO PHASE FLOW PRESSURE DROP
CORRELATING PARAMETERS

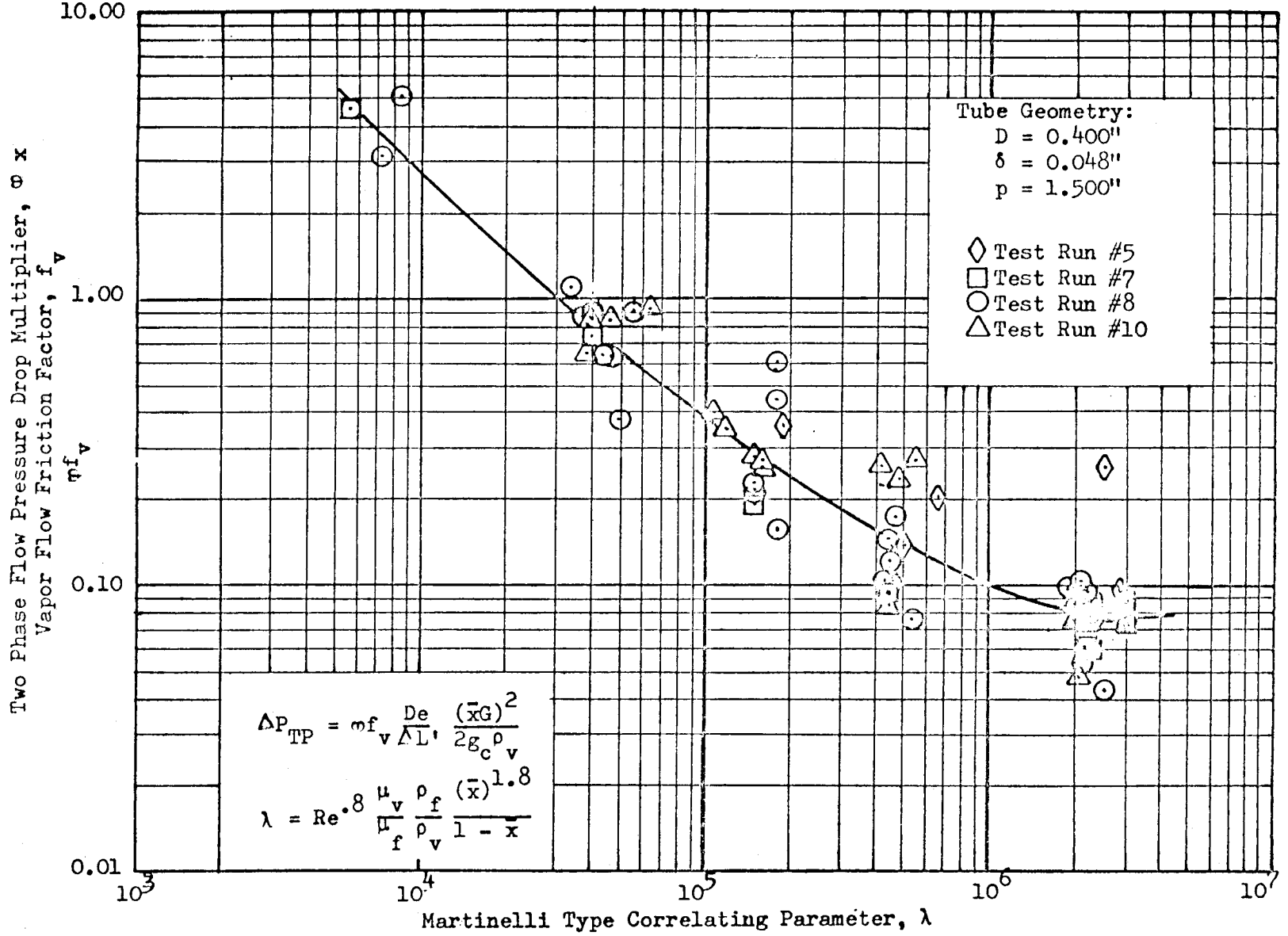


Figure 6.0-4

CL-4 BOILER TEST
PLUG INSERT VAPOR SECTION PRESSURE DROP
VS PLUG INSERT VAPOR EXIT QUALITY

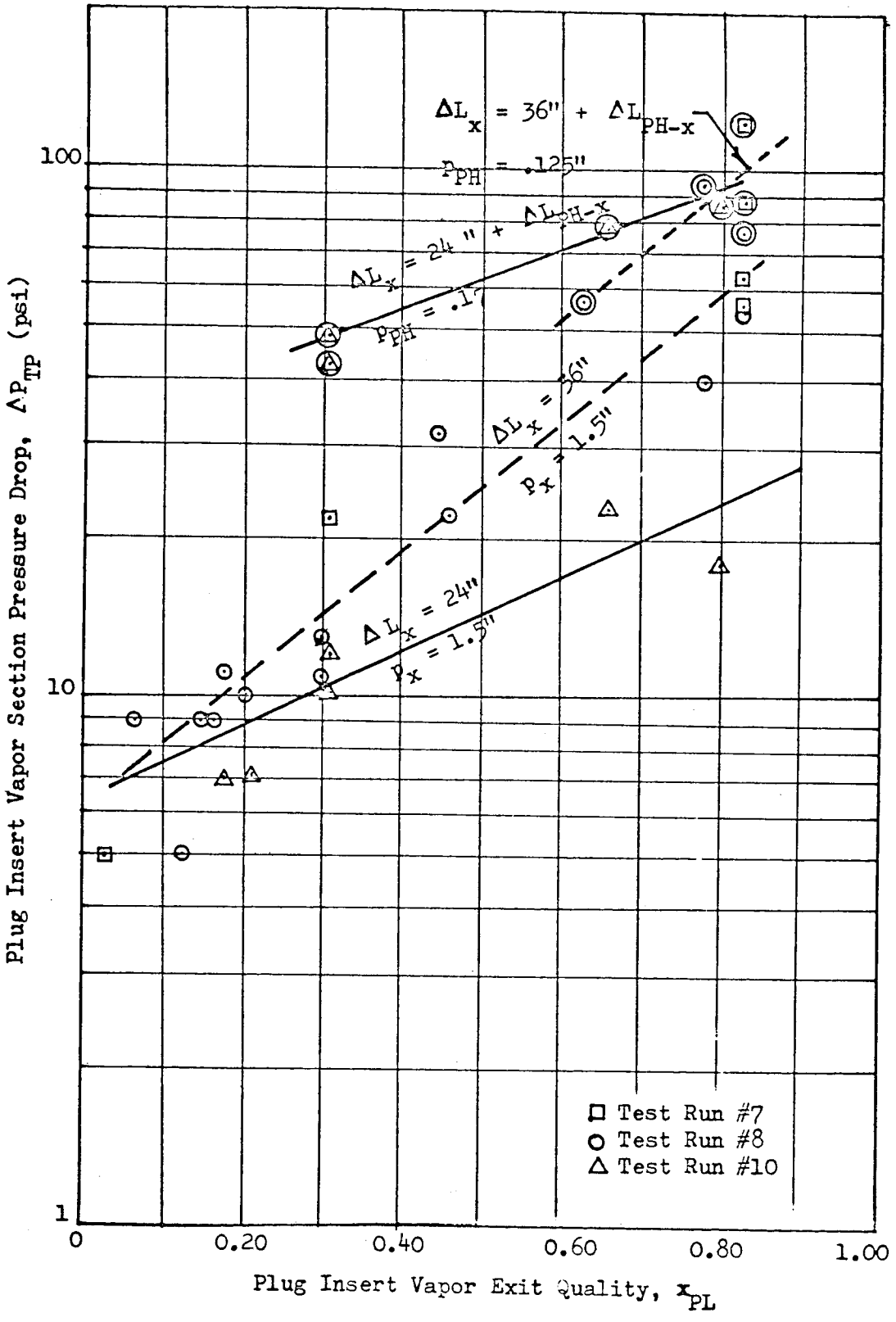


Figure 6.0-5

CL-4 BOILER TEST
INITIAL BOILING HEAT FLUX VS
PINCH POINT TEMPERATURE DIFFERENCE

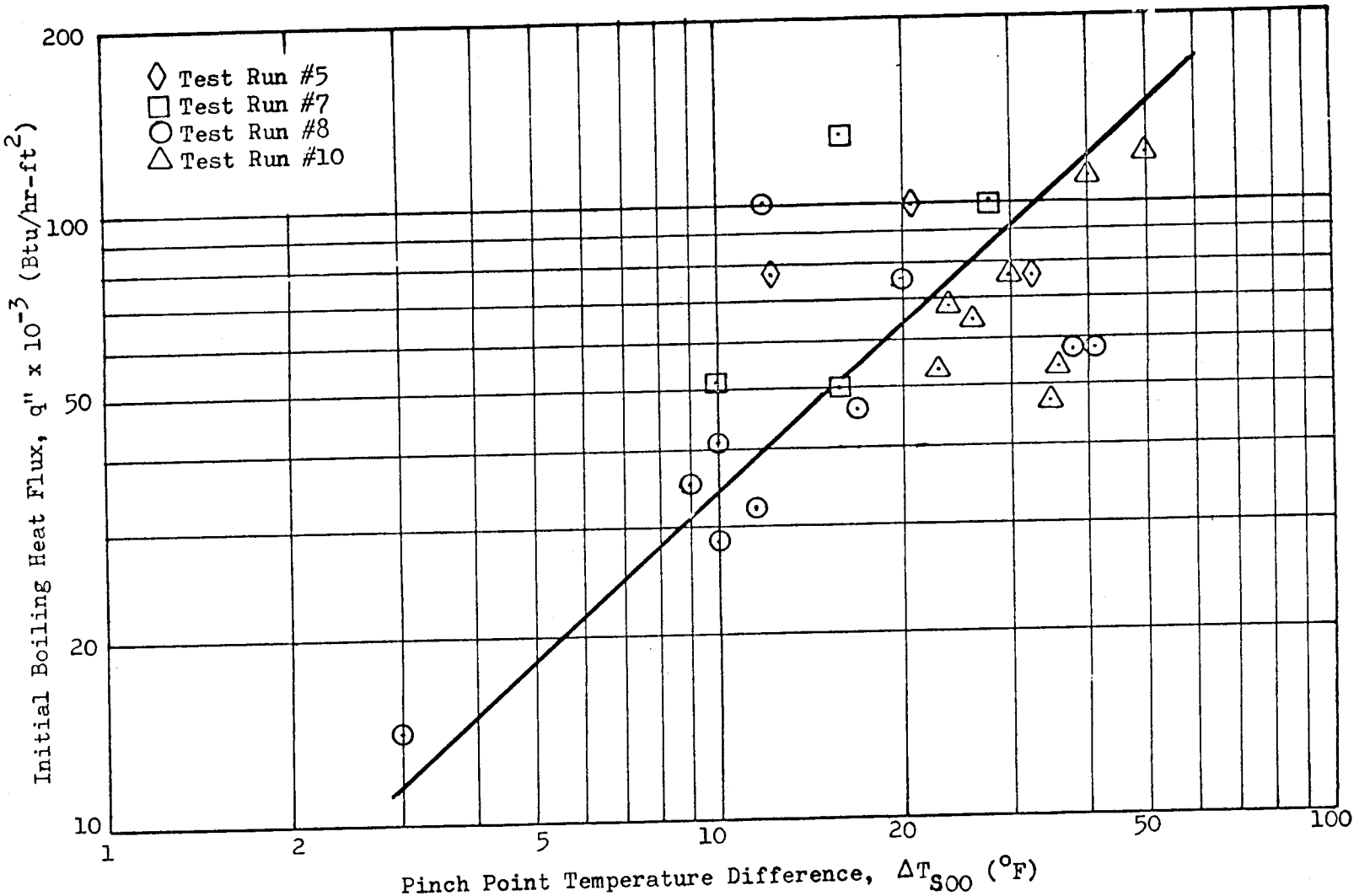


Figure 6.0-5

CL-4 BOILER TEST
LOCAL BOILING - q" vs ΔT_M @ $\bar{x}$ = .10

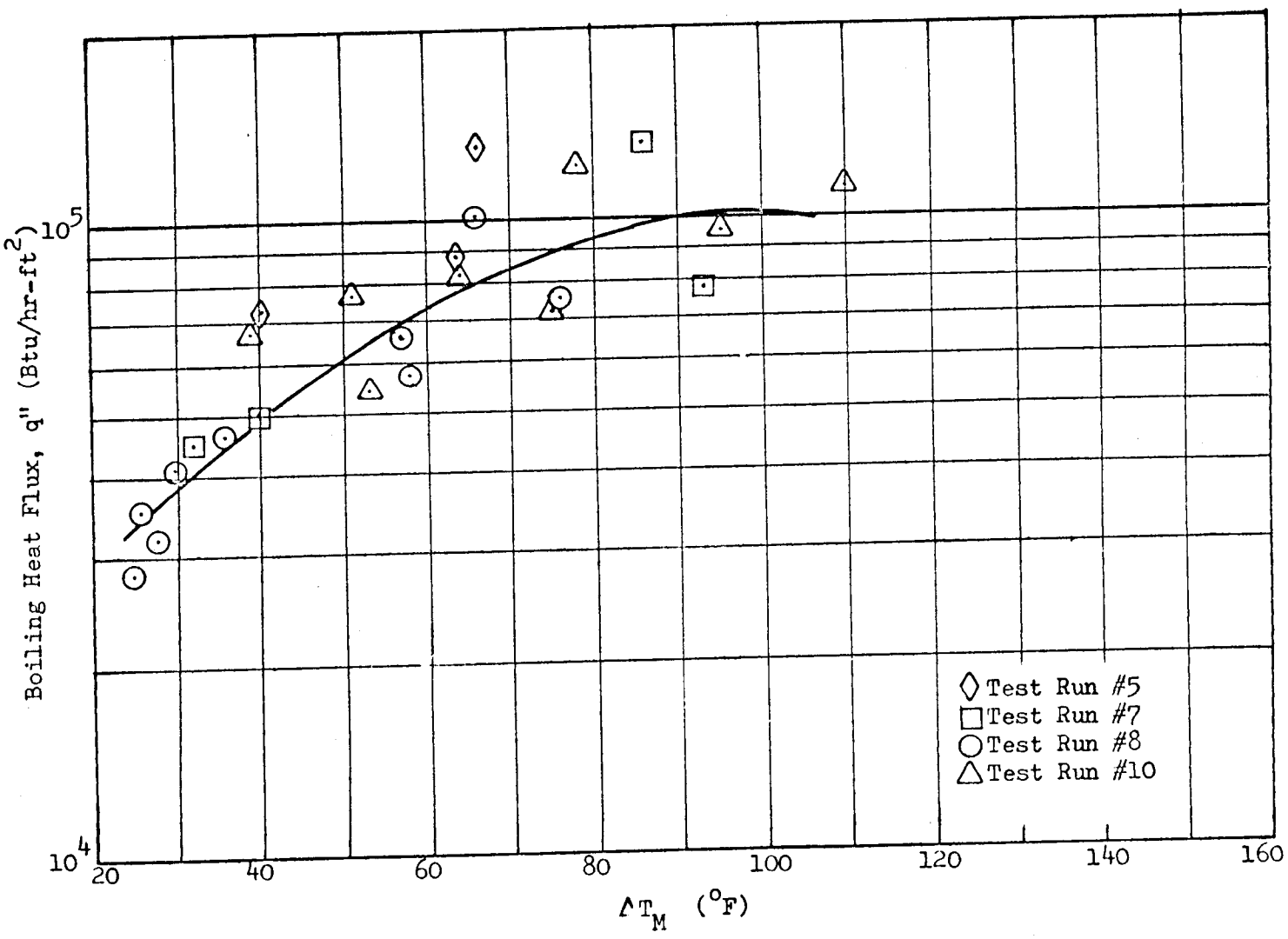


Figure 6.0-7

CL-4 BOILER TEST
LOCAL BOILING - q" vs ΔT_M @ $\bar{x}$ = .30

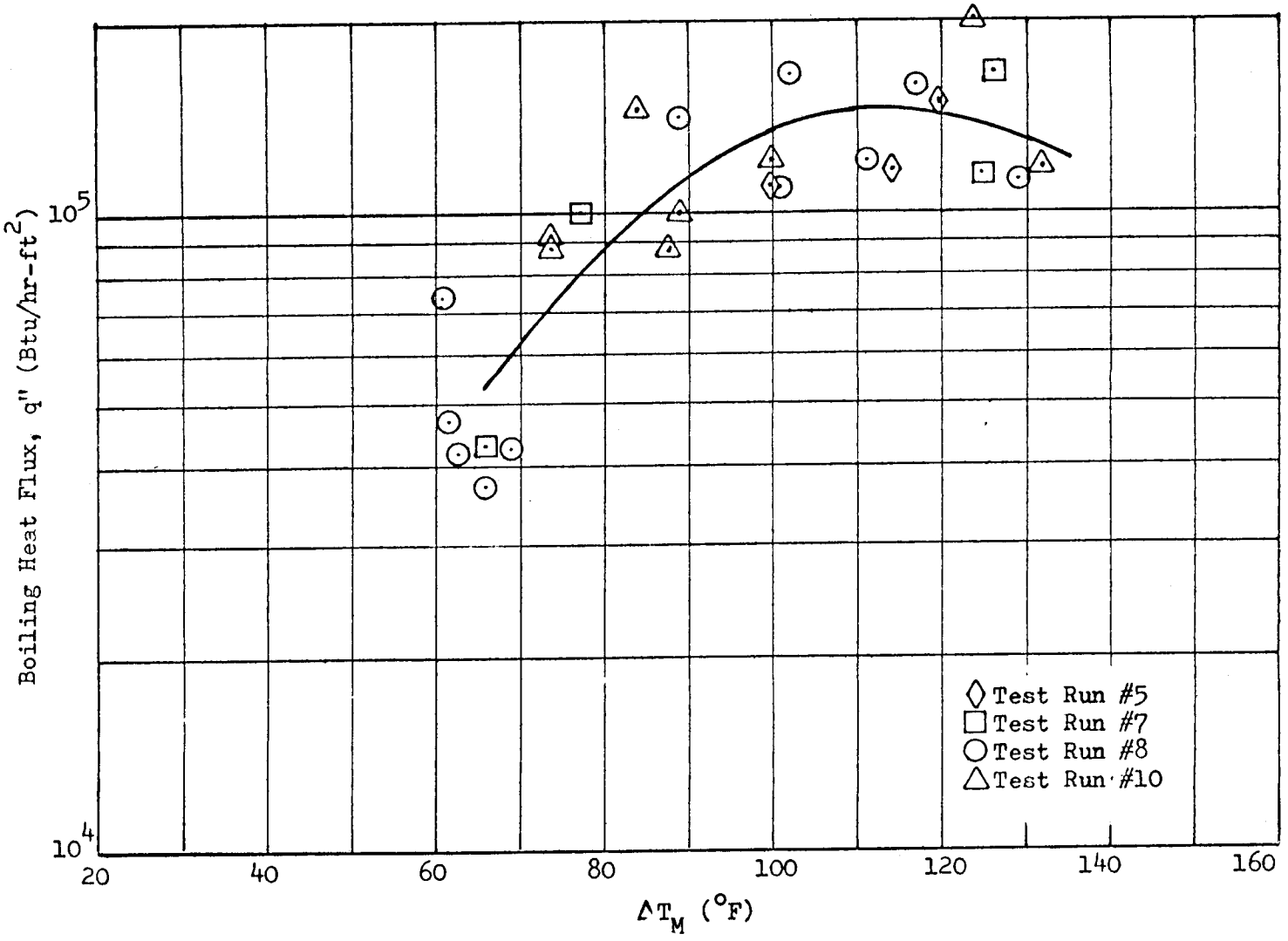


Figure 6.0-8

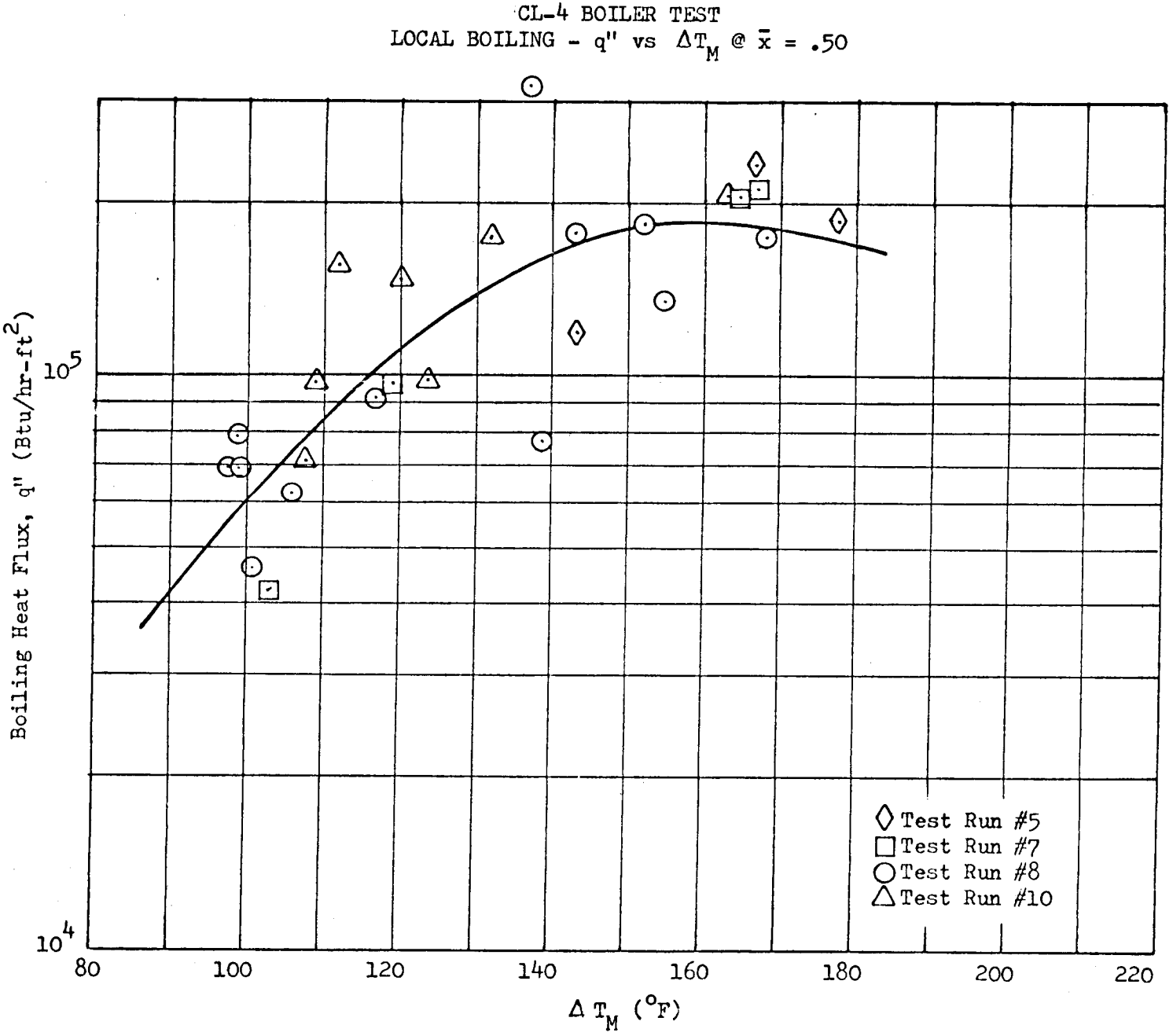

CL-4 BOILER TEST
LOCAL BOILING - q" vs ΔT_M @ $\bar{x}$ = .50
Boiling Heat Flux, q" (Btu/hr-ft^2)
10^5
10^4
80
100
120
140
160
180
200
220
ΔT_M (°F)
Test Run #5
Test Run #7
Test Run #8
Test Run #10

Figure 6.0-9

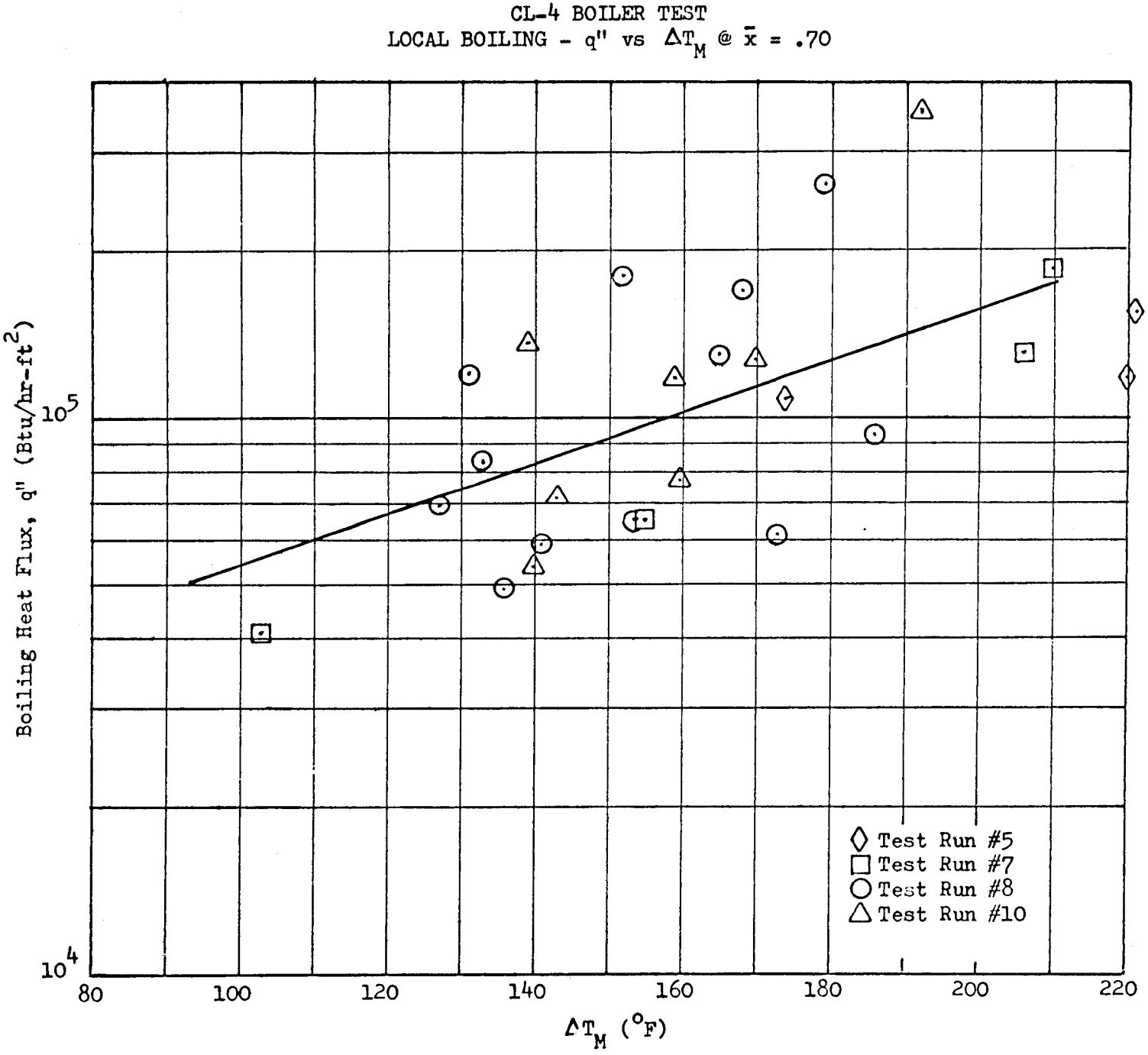

CL-4 BOILER TEST
LOCAL BOILING - q" vs ΔT_M @ $\bar{x}$ = .70
Boiling Heat Flux, q" (Btu/hr-ft^2)
10^5
10^4
80
100
120
140
160
180
200
220
ΔT_M (°F)
Test Run #5
Test Run #7
Test Run #8
Test Run #10

Figure 6.0-10

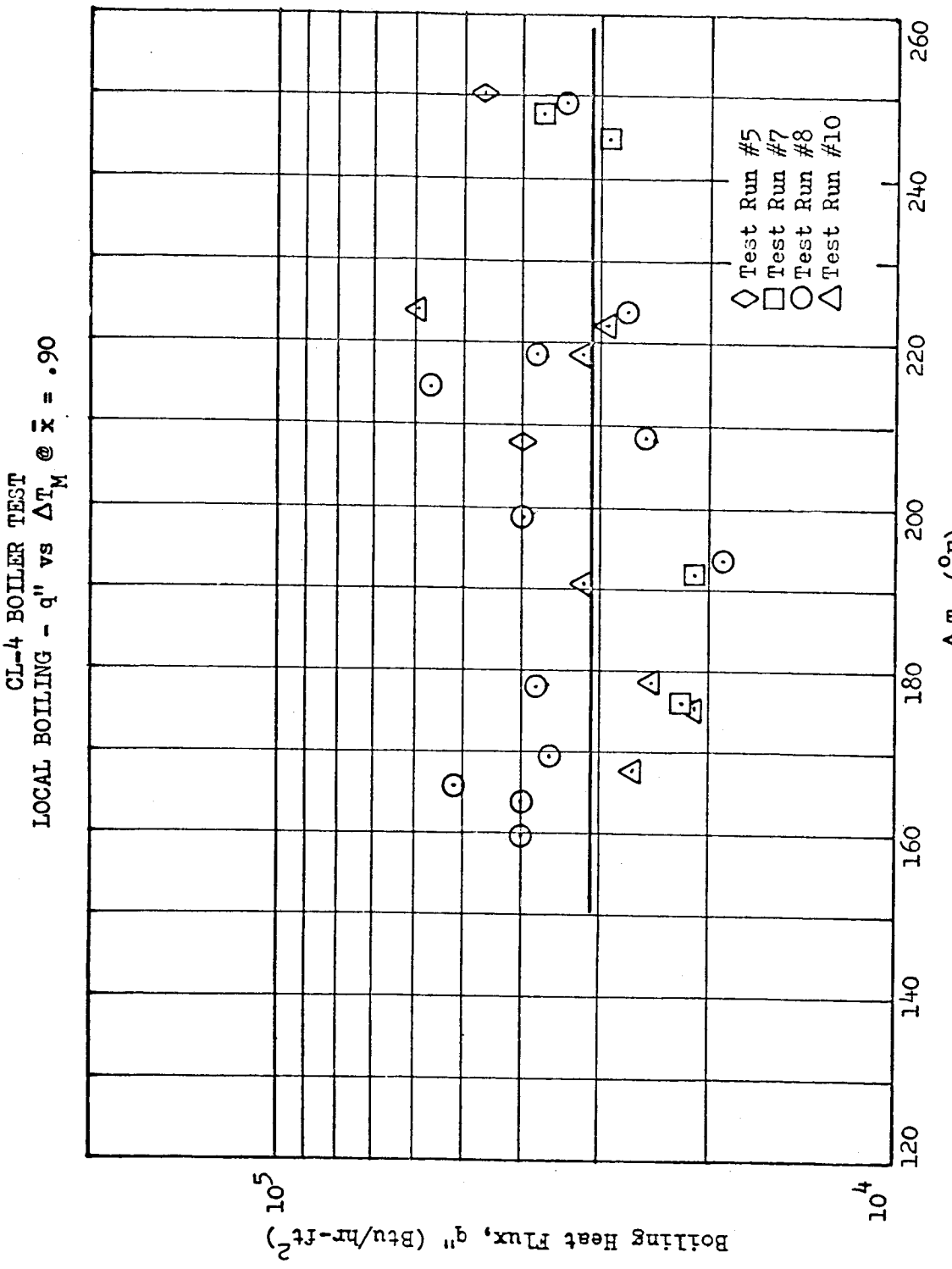

CL-4 BOILER TEST
LOCAL BOILING - q" vs ΔT_M @ $\bar{x}$ = .90
Boiling Heat Flux, q" (Btu/hr-ft^2)
10^5
10^4
120
140
160
180
200
220
240
260
ΔT_M (°F)
Test Run #5
Test Run #7
Test Run #8
Test Run #10

Figure 6.0-11

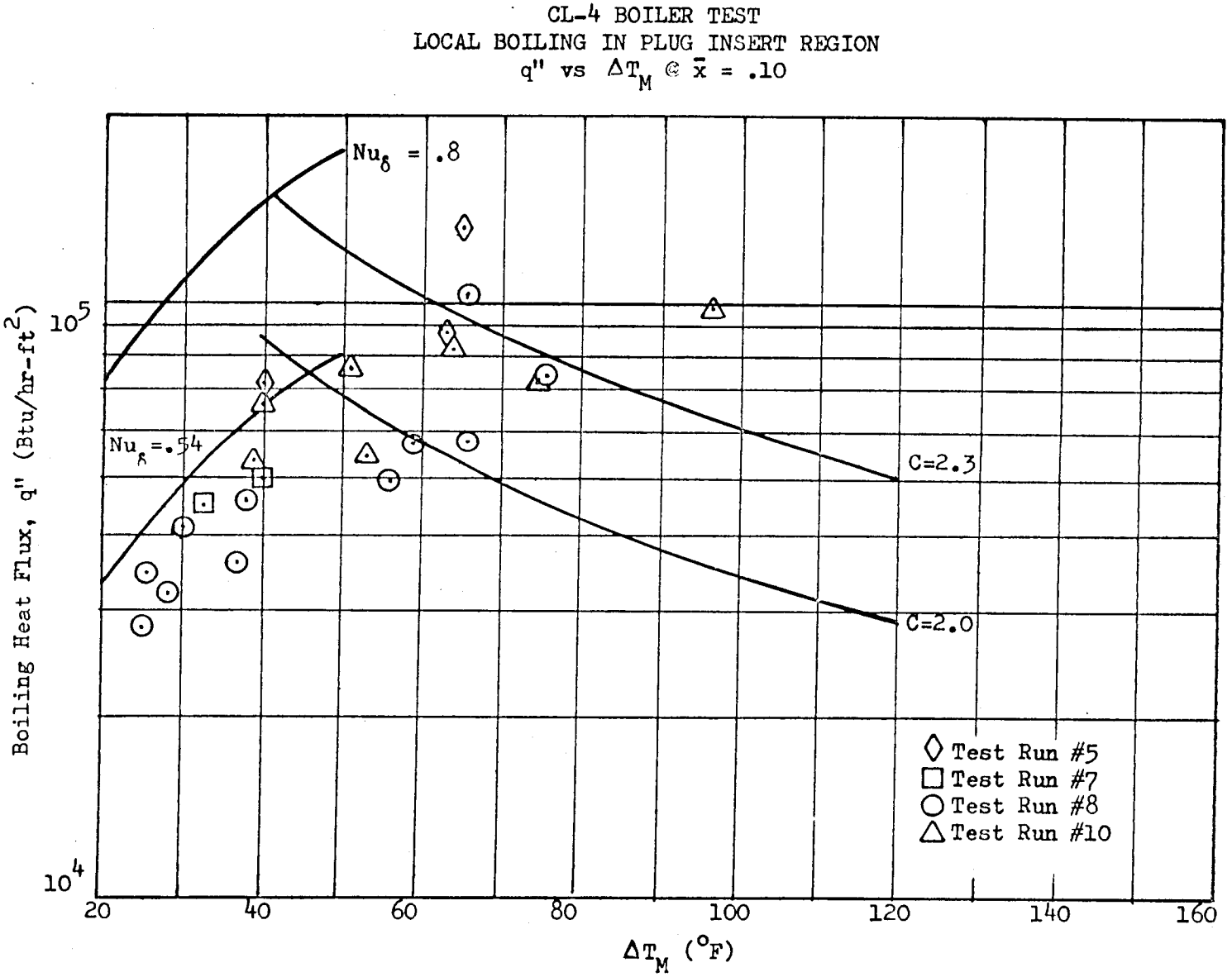

CL-4 BOILER TEST
LOCAL BOILING IN PLUG INSERT REGION
q" vs ΔT_M @ $\bar{x}$ = .10
Nu_δ = .8
Nu_δ = .54
C=2.3
C=2.0
Test Run #5
Test Run #7
Test Run #8
Test Run #10
Boiling Heat Flux, q" (Btu/hr-ft^2)
10^5
10^4
20
40
60
80
100
120
140
160
ΔT_M (°F)

Figure 6.0-12

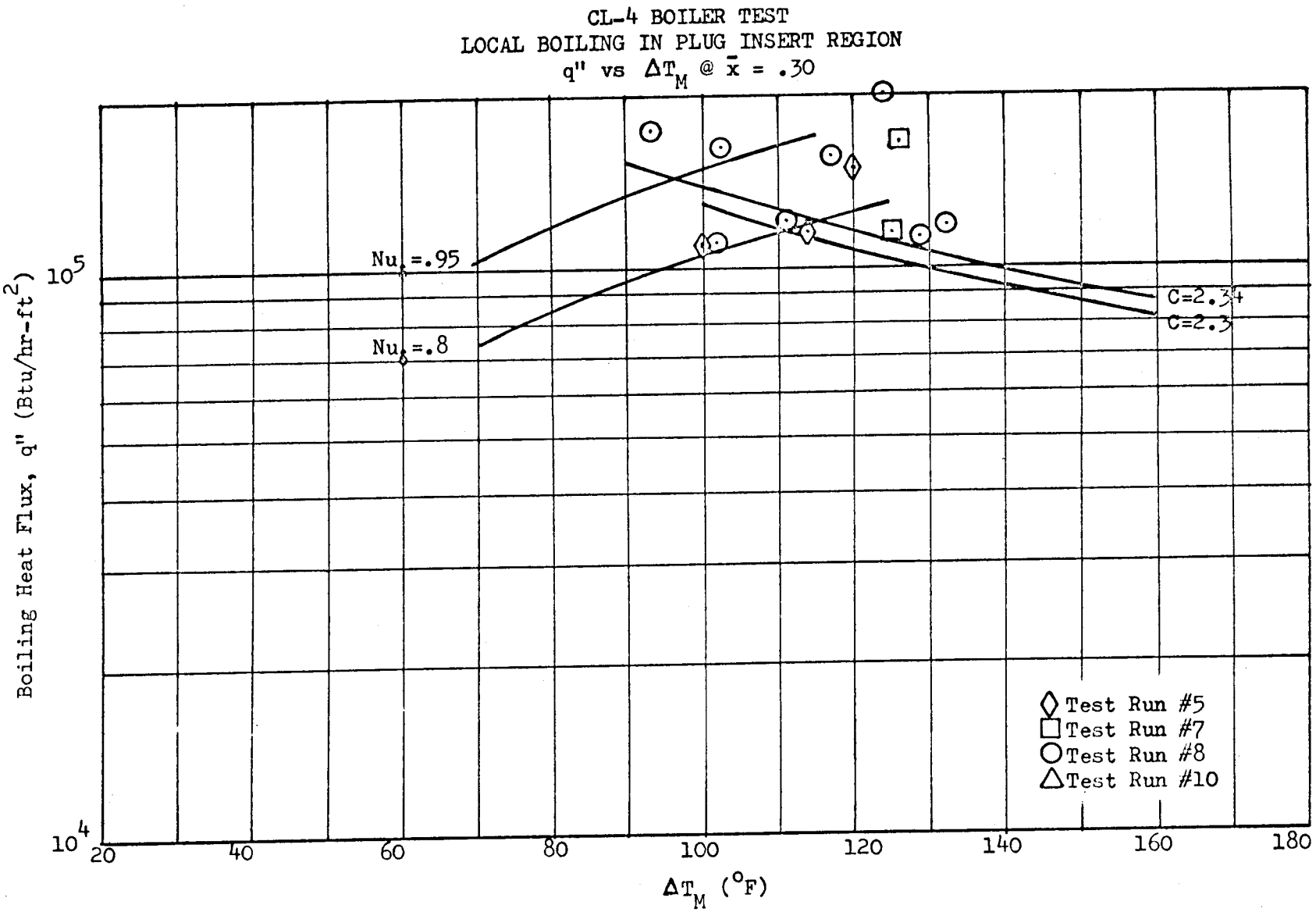

CL-4 BOILER TEST
LOCAL BOILING IN PLUG INSERT REGION
q" vs ΔT_M @ $\bar{x}$ = .30
Boiling Heat Flux, q" (Btu/hr-ft^2)
10^5
10^4
Nu_x =.95
Nu_x =.8
C=2.34
C=2.3
Test Run #5
Test Run #7
Test Run #8
Test Run #10
20
40
60
80
100
120
140
160
180
ΔT_M ($^\circ$F)

Figure 6.0-13

CL-4 BOILER TEST
LOCAL INTERMITTENT CONTACT BOILING IN UNPLUGGED TUBE REGION
q" vs ΔT_M @ $\bar{x}$ = .30

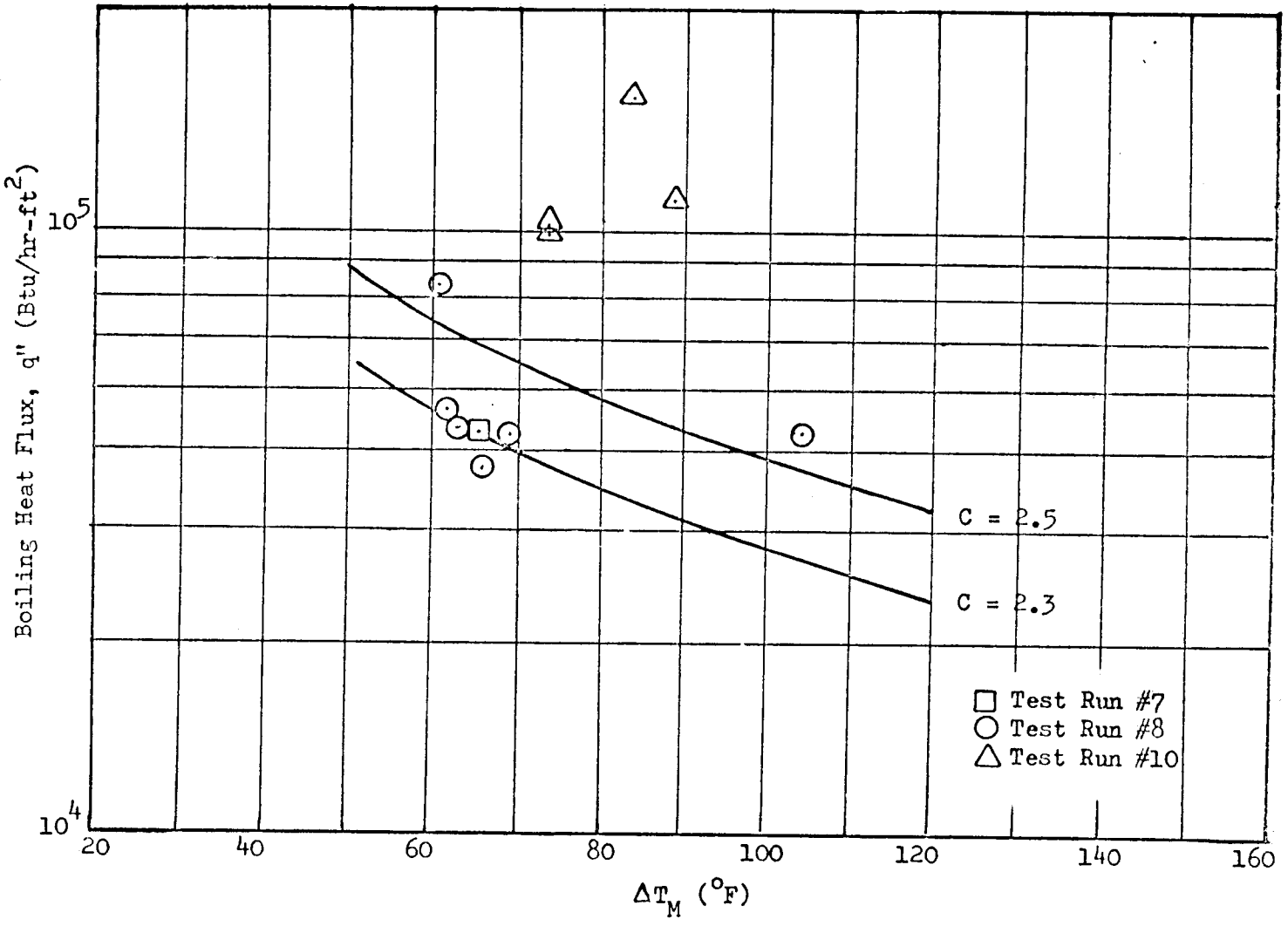


Figure 6.0-14

CL-4 BOILER TEST
LOCAL CONTACT BOILING IN PLUG INSERT REGION
q'' vs ΔT_M @ $\bar{x}$ = .50

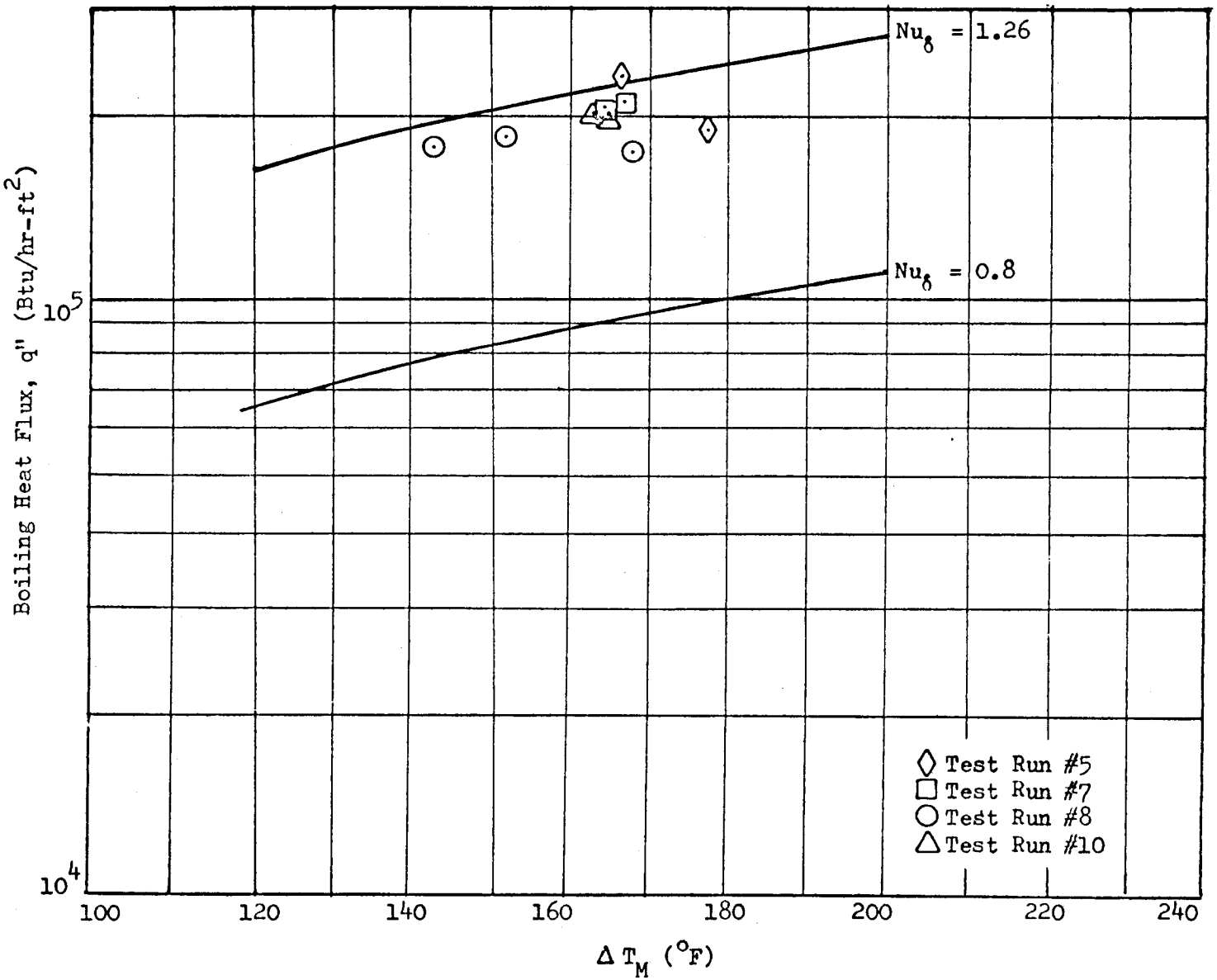


Figure 6.0-15

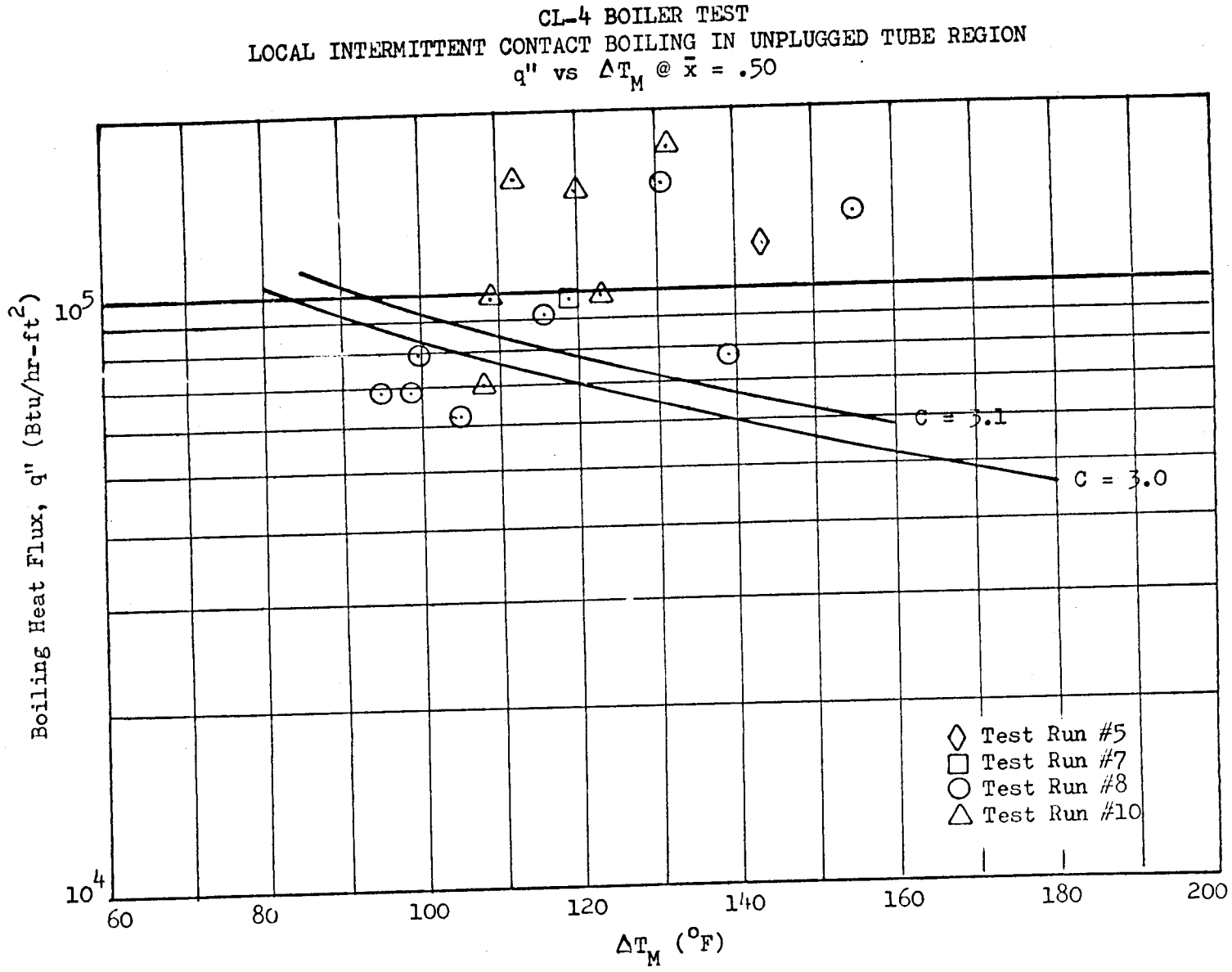

CL-4 BOILER TEST
LOCAL INTERMITTENT CONTACT BOILING IN UNPLUGGED TUBE REGION
q" vs ΔT_M @ $\bar{x}$ = .50
Boiling Heat Flux, q" (Btu/hr-ft^2)
10^5
10^4
C = 3.1
C = 3.0
Test Run #5
Test Run #7
Test Run #8
Test Run #10
60
80
100
120
140
160
180
200
ΔT_M (^{o}F)

Figure 6.0-16

CL-4 BOILER TEST
LOCAL CONTACT BOILING IN PLUG INSERT REGION
q" vs ΔT_M @ $\bar{x}$ = .70

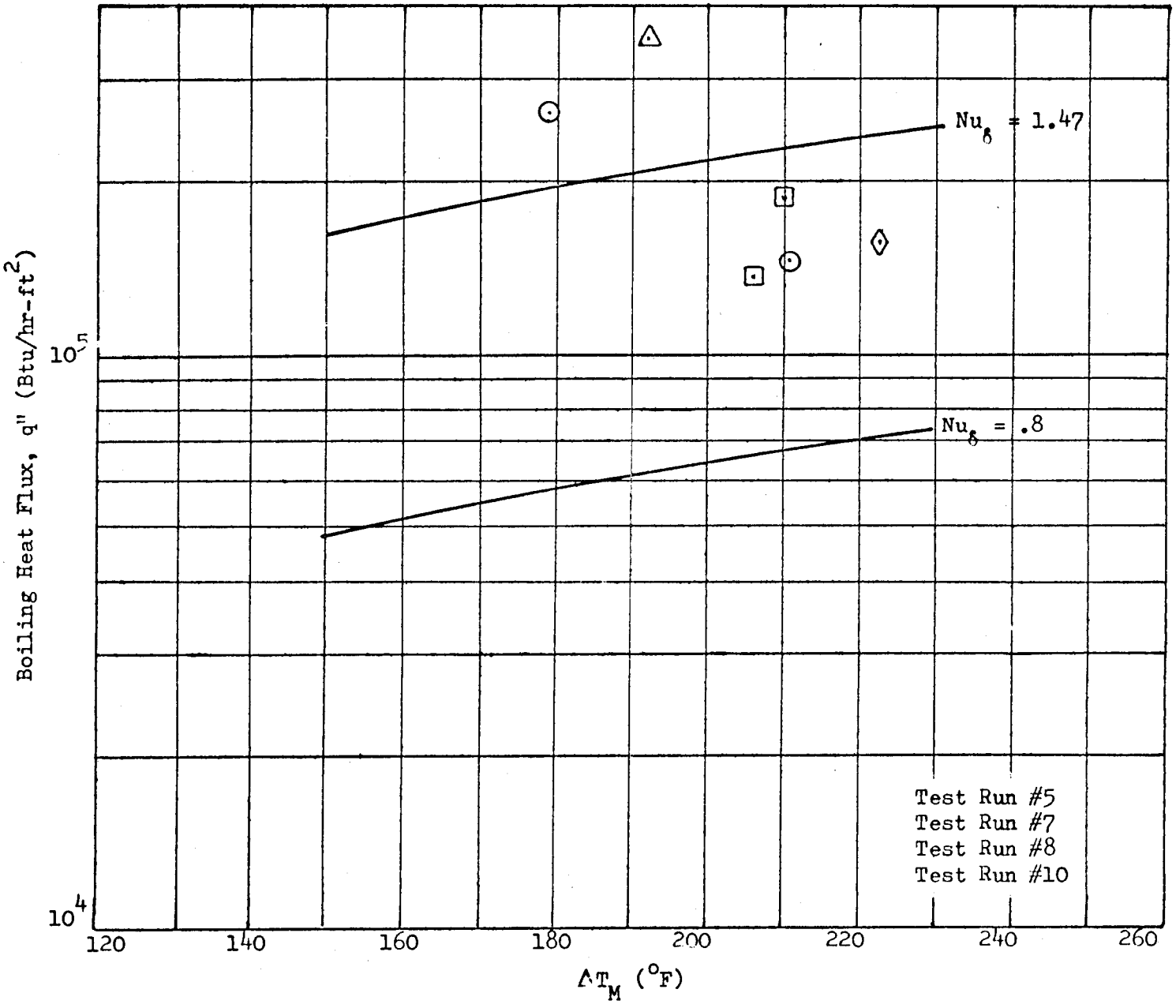


Figure 6.0-17

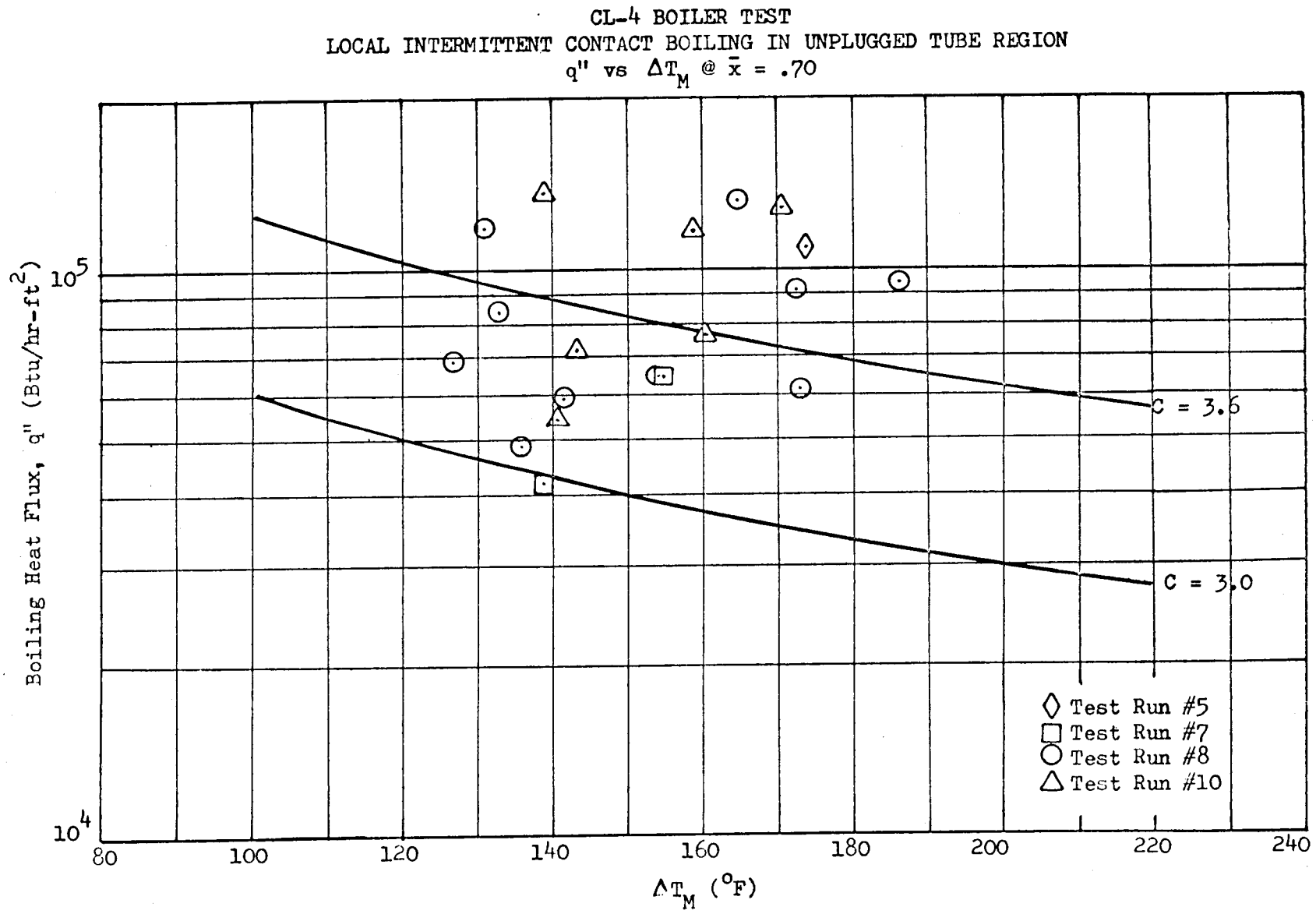

CL-4 BOILER TEST
LOCAL INTERMITTENT CONTACT BOILING IN UNPLUGGED TUBE REGION
q" vs ΔT_M @ $\bar{x}$ = .70
Boiling Heat Flux, q" (Btu/hr-ft^2)
10^5
10^4
80
100
120
140
160
180
200
220
240
ΔT_M (^{o}F)
C = 3.6
C = 3.0
Test Run #5
Test Run #7
Test Run #8
Test Run #10

Figure 6.0-18

CL-4 BOILER TEST
LOCAL FILM BOILING IN UNPLUGGED TUBE REGION
q" vs ΔT_M @ $\bar{x}$ = .90

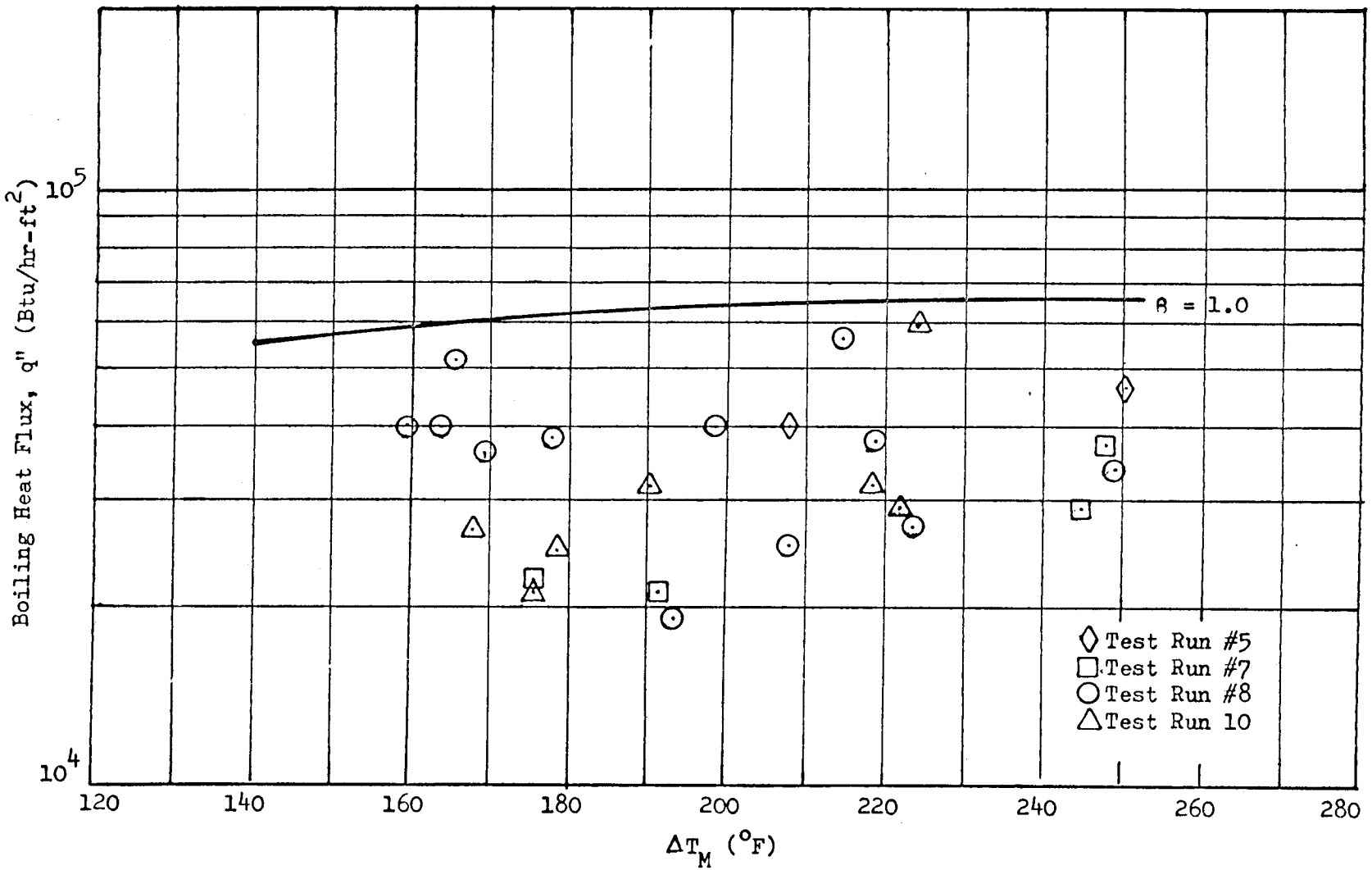


Figure 6.0-19

CL-4 BOILER TEST
TYPICAL BOILING HEAT FLUX REPRESENTATION
THROUGHOUT THE BOILER VAPOR QUALITY SECTION

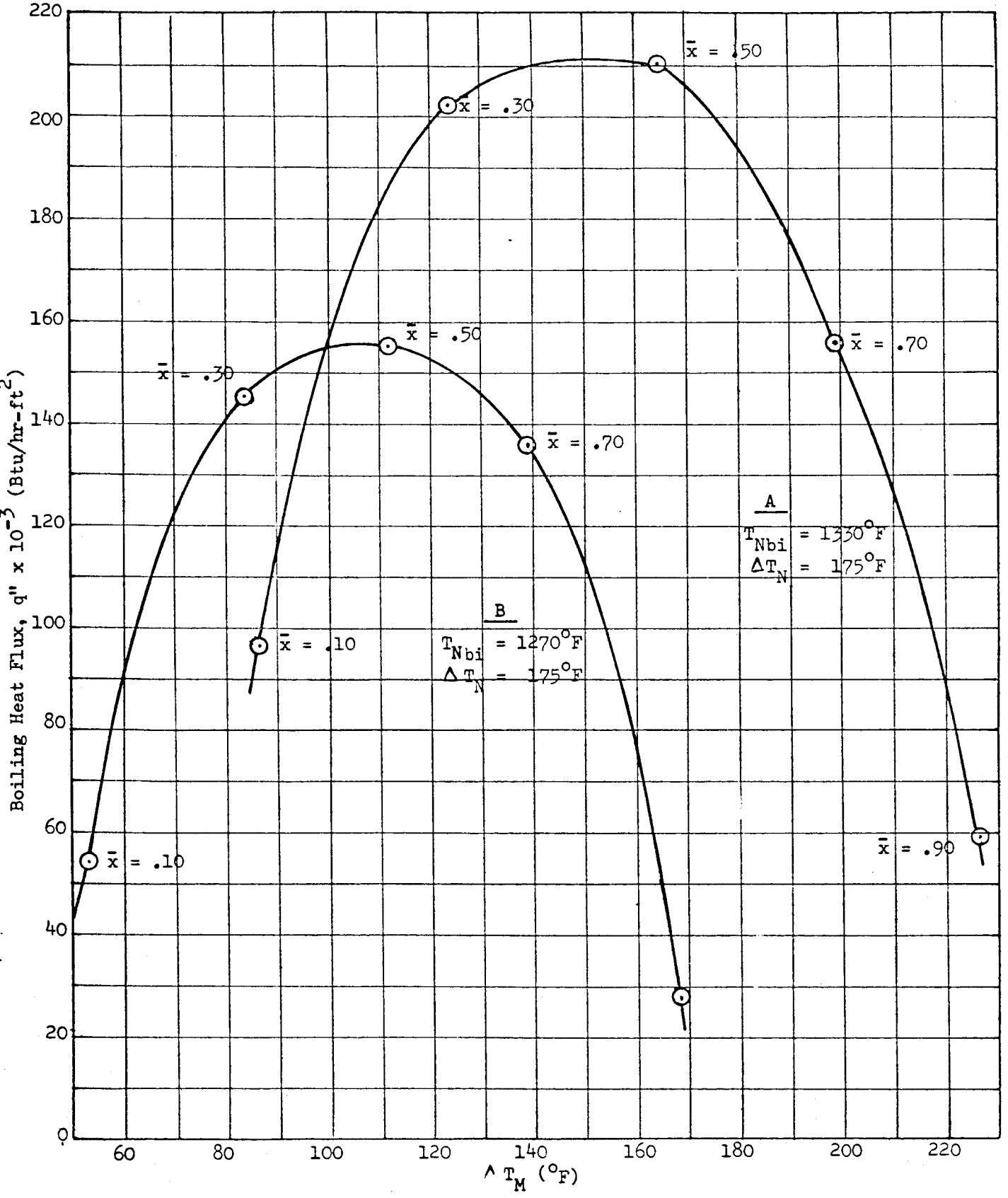


Figure 6.0-20

VII. CONCLUSIONS

The introduction of a preheat section plug insert providing elevated liquid phase velocity at the liquid-vapor interface location demonstrates significant improvement in the boiler conditioning effect. As shown in Appendix C, Figures C-3 thru C-5, the obtained boiler NaK temperature profiles are approaching the design prediction indicated in Figure C-3. It is postulated that elevated liquid phase velocities at the liquid-vapor interface significantly reduce or even completely eliminate the convective mercury boiling transition regime between the liquid-vapor interface and the fully established two-phase vortex flow pattern.

The boiler conditioning time is apparently dependent upon the cleanliness of the internal wall surface of the mercury flow passage. To define the surface cleanliness in conjunction with boiler conditioning effect, a better understanding of surface physics and chemistry is needed. Up-to-date experience suggests that tight plug insert geometries provided in the boiler preheat section, as well as in the low vapor quality section are capable of accelerating the boiler conditioning effect by several orders of magnitude when the boiler mercury flow passage is cleaned by established[4] methods prior to mercury injection. This method involves flushing with strong caustic solution, followed by flushing with Alionox detergent solution.

The test of two tight preheat section plug insert geometries providing liquid phase velocity of 4.5 and 6.5 ft/sec at the liquid-vapor interface accordingly resulted in very stable boiler performance characteristics. As compared to a loose preheat section plug insert geometry (u_L = .8 ft/sec) , the tight plug inserts demonstrate reduction in boiler exit pressure fluctuations by an order of magnitude; e.g., the comparative boiler exit pressure fluctuations are $\pm$ 10 and $\pm \frac{1}{2}$ psia.

Most effective boiling heat transfer was obtained from extended length plug insert geometries (Test runs No. 5, 7 and 8) where the plug insert end point vapor quality and vapor phase velocity were up to 80% and 180 ft/sec, respectively, at high NaK temperature schedules. At low NaK temperature schedules the same parameters were found to be 45% and 100 ft/sec, respectively. Aside from the high pressure drop penalty, it is felt that under these dynamic conditions most effective mist or even fog flow can be expected at the plug insert end point and thus the droplet carry-over thru the excess superheat length is minimized. It is obvious that high vapor flow velocity; e.g., 180 ft/sec, at the plug insert end point provides elevated vapor flow velocity; e.g. 40 ft/sec in the unplugged tube next to the

plug insert end point. Thus effective vortex flow takes place in the unplugged tube. As a result of droplet radial acceleration in this flow regime the droplets are forced against the tube wall and effectively vaporized.

In accordance with the early vortex two-phase flow establishment definition by means of Weber number ($We = \frac{\delta_o \rho_v u_v^2}{\sigma}$) as proposed by Reference 1; e.g. $\rho_v u_v^2 \geq 142$, a certain vapor phase velocity (u_v) must be obtained in order to carry droplets of diameter δ_o in the vapor stream. In the case of low liquid phase velocities (u_L = .8 ft/sec) the initial boiling is under the influence of the 1 g gravity field because of the absence of sufficient liquid and vapor phase velocity effects. Considerable transition length accompanied by liquid slugging is needed until a fully developed vortex two-phase flow regime ($u_v \geq \sqrt{\frac{142}{\rho_v}}$) is established. In the case of elevated liquid phase velocities ($u_L \cong u_v$ = 6.2 ft/sec) the liquid-vapor interface disintegration and initial boiling may take place in a vortex type flow pattern, where the liquid spheroids are forced against the tube wall thus producing effective initial vapor generation. This design approach suggests that elevated liquid phase velocities (u_L) at the liquid-vapor interface location initially accelerate the highly deficient vapor phase ($\bar{x} \rightarrow 0$), simultaneously promoting effective boiling heat transfer rates. The latter in turn do elevate the vapor phase velocity ($u_v \rightarrow u_L \rightarrow u_{v\text{-}cr} = \sqrt{\frac{142}{\rho_v}}$) causing finally the entrainment of liquid drops into the vapor stream. It is postulated that this early vortex two-phase flow boiling regime is desirable for boiler operation in zero or adverse gravity environments.

The two-phase flow pressure data, as shown in Figures 6.0-2 thru 6.0-4, are in non-dimensional form, and compare reasonably well with similar data scatter in Reference (1). It is therefore felt that these results can be used to evaluate the pressure drop conditions of other tube sizes and plug insert geometries considered for SNAP-8 and similar Rankine cycle power conversion systems. Empirically determined gas flow frictional pressure drop coefficients are permitting the analysis of two-phase flow pressure drop using the Martinelli parameter for relatively complex flow passage geometries.

The results derived from an analysis of the local boiling heat transfer test data reveal reasonable agreement with the dropwise dry wall boiling formulation as proposed by Reference (1). The boiling heat transfer rates can be adequately predicted from proposed semi-empirical correlation. The test data comarison with the reference information is shown in Figures 6.0-12 thru 6.0-19. The discrepancies are primarily in the test data areas referring to the plug insert vapor quality section. These discrepancies are caused by the introduction of the helical flow passage geometric values into the referenced boiling heat transfer correlations. These correlations were established for round tubular flow passages with swirl wire in them. The plug insert section flow passage can be analytically treated on the basis of its equivalent or hydraulic diameter only.

The inaccuracies in NaK temperature profile interpretation and in analytical estimates in lieu of missing test information are the primary reasons for the test data point scatter. The instrumentation difficiencies were particularly felt in the boiler mercury inlet end region. The plot of mercury temperature rise in the preheat section in terms of mercury tube length was not available. Consequently, the true position of the liquid-vapor interface could not be established.

The existing NaK loop flow and heat input capacity placed serious limitations upon the scope of the test objectives. The boiler operation, therefore, was limited to 80% of its design capacity. The test results also show that the length of this boiler has been overdesigned by at least a factor of two.

VIII. RECOMMENDATIONS

To eliminate boiler deconditioning, means must be provided to prevent oxidation of the tube wall or the entrance of oil or other substances into the mercury tubes during the system's assembly, operation or shutdown.

Clarification is needed in regard to mercury liquid and vapor phase thermal conductivities to be used for the SNAP-8 operating conditions. As can be seen from proposed semi-empirical correlations[1] the Husselt's number for intermittent contact boiling regime is proportional to $(\frac{k_v}{k_f})^4$. Comparison of Reference (3) data with WADD data indicates significant differences in their numerical values; e.g., $(\frac{k_v}{k_f})^4_{\text{Ref.(3)}} = 1.9 \times 10^{-12}$; $(\frac{k_v}{k_f})^4_{\text{WADD}} = 6.0 \times 10^{-12}$.

To investigate the boiler's off design operating characteristics, the nominal NaK loop flow rate and heat input capacity have to be overdesigned by a factor of 2 and 1.25, respectively.

Long duration continuous tests up to several thousands of hours are required on SNAP-8 boilers to establish the time effects on boiler performance and their structural reliability.

More sophisticated instrumentation is required to investigate and define the thermal and dynamic design aspects in the boiler plug insert section. These requirements can be detected from the curves shown in Figure 6.0-1.

In order to verify the derived non-dimensional boiler design formulations additional experimental boilers of different mercury flow passage sizes and internal geometries should be built and tested under SNAP-8 operating conditions. The evaluation of these results shows uncertainties arising from limited instrumentation, in regard to true liquid-vapor interface location. True temperature and pressure profile representations must be obtained throughout the length of the boiler plug insert section.

REFERENCES

1. The SNAP-2 Power Conversion System Topical Report No. 17, Mercury Boiling Research, TRW Report No. ER-4833, Oct. 1964.

2. L. T. Clark and M. F. Parkman, Effects of Additives on Wetting During Mercury Pool Boiling Heat Transfer, ASME, 64-WA/HT-22.

3. Properties of SNAP-8 Fluids, NaK and Mercury, ET-378, Aerojet-General Corp., March 1964.

4. Cleaning of SNAP-8 Power Conversion System Components Prior to Final Assembly - Method II, AGC-10319/6

5. M. K. Wong, Corrosion Test Loop Operation Manual, Aerojet-General Nucleonics Report No. AN-SNAP-64-177, 16 February 1964

NOMENCLATURE

C	-	Constant
D	-	Mercury tube diameter
De	-	Equivalent tube diameter
f	-	Flow friction factor
G	-	Specific mass flow
g_c	-	Standard acceleration at sea level
h	-	Heat transfer coefficient
h_{fv}	-	Latent heat
h_N	-	NaK side film coefficient
k	-	Thermal conductivity
k_w	-	Tube material thermal conductivity
$\Delta L'$	-	Axial tube length
Nu	-	Nusselt number
Nu_δ	-	Droplet Nusselt number
P_{Hbi}	-	Mercury inlet pressure
P_{Hbo}	-	Mercury unit pressure
P_{00}	-	Pressure at liquid vapor interface
P_1	-	Preheat section end point pressure
P_2	-	Plug insert end point pressure
q''	-	Heat flux
Re	-	Reynolds number
r_m	-	Log mean radius
r_o	-	Tube outside radius
t	-	Tube wall thickness
ΔT_{00}	-	Temperature difference at liquid-vapor interface
ΔT_{N00}	-	NaK temperature at $x = 0$
ΔT_{S00}	-	Saturation temperature at liquid-vapor interface

NOMENCLATURE (Cont.)

U	-	Overall heat transfer coefficient
x	-	Vapor quality, vapor weight/total weight
$\bar{x}$	-	Mean vapor quality

GREEK SYMBOLS

α	-	Swirl wire angle
β	-	Nu (actual)/Nu_{δ}(film-sphere)
δ_o	-	Initial droplet diameter, swirl wire diameter
λ	-	Martinelli correlating parameter
ρ	-	Density
ϕ	-	Two-phase flow pressure drop factor, $\Delta P_{TP}/\Delta P_v$
μ	-	Viscosity

SUBSCRIPTS

C	-	Contact boiling
F	-	Film boiling
IC	-	Intermittent contact boiling
M	-	Mean
TP	-	Two-phase
cr	-	Critical
f	-	Liquid at saturation temperature
v	-	Vapor

APPENDIX A

RESULTS OF CL-4 BOILER TEST DATA REDUCTION

TEST RUN NO.		5-161C	5-171	5-181	7-1C2	7-2C2	7-3C2	7-4C2	8-1C2	8-2C2	8-3C2
PLUG INSERT NO.		3	3	3	5	5	5	5	6	6	6
------- TEST DATA --------											
WN	LB/HR	2025.00	2055.00	2040.00	2055.00	2050.00	1830.00	1800.00	2055.00	1770.00	2055.00
TN3I	DEG-F	1345.00	1295.00	1310.00	1310.00	1310.00	1280.00	1280.00	1309.00	1275.00	1300.00
TN3O	DEG-F	1142.00	1095.00	1125.00	1130.00	1134.00	1080.00	1080.00	1104.00	1075.00	1110.00
DELTN	DEG-F	203.00	190.00	185.00	180.00	176.00	200.00	200.00	205.00	200.00	190.00	
WH	LB/HR	492.00	516.00	500.00	514.00	497.00	497.00	497.00	500.00	503.00	500.00
TH3I	DEG-F	500.00	500.00	500.00	490.00	500.00	510.00	505.00	490.00	520.00	490.00
TH3O	DEG-F	1260.00	1205.00	1230.00	1230.00	1230.00	1210.00	1210.00	1220.00	1210.00	1225.00
PH3I	PSIA	435.00	365.00	395.00	432.00	455.00	406.00	393.00	402.00	383.00	403.00
P1	PSIA	378.00	326.00	345.00	300.00	298.00	296.00	307.00	302.00	305.00	312.00
P2	PSIA	252.00	258.00	235.00	237.00	242.00	274.00	303.00	268.00	292.00	290.00
PH3O	PSIA	152.00	154.00	116.00	135.00	137.00	138.00	236.00	170.00	215.00	196.00
------ HEAT BALANCE ------											
QN	BTU/HR	83425.75	81994.50	79254.00	77679.00	75768.00	76850.00	75630.00	38467.75	74340.00	81994.50
QHC	BTU/HR	72165.57	73522.37	72985.76	75184.32	72534.96	72096.31	72149.34	73967.50	72786.01	74013.00
QHL1	KW	4.15	2.48	1.84	0.73	0.95	1.40	1.01	4.25	0.45	2.34
WNIET	LB/HR	1592.84	1842.86	1878.56	1980.00	1962.53	1716.58	1717.84	1718.18	1733.00	1854.96
----- PREHEAT SECTION ----											
DEPH	FT	0.0052	0.0052	0.0052	0.0049	0.0049	0.0049	0.0049	0.0049	0.0049	0.0049
DLPHC	FT	1.00	1.25	1.25	0.90	0.80	1.25	1.25	1.25	1.25	1.25
DPPH	PSI	30.00	37.00	51.00	72.00	68.00	110.00	86.00	100.00	78.00	91.00
PPH	PSIA	435.00	329.00	345.00	360.00	387.00	296.00	307.00	302.00	305.00	312.00
TN2I	DEG-F	1171.00	1120.00	1150.00	1154.00	1157.00	1106.00	1106.00	1134.00	1101.00	1137.00
TS2I	DEG-F	1150.40	1107.68	1117.20	1125.60	1140.72	1089.12	1095.92	1098.12	1094.80	1098.72
DLT30	DEG-F	20.60	12.32	32.80	24.40	16.28	16.88	10.08	40.88	6.20	38.28
QPHC	BTU/HR	10369.90	9993.30	10029.50	10617.70	10349.23	9354.24	9544.84	10775.70	9396.54	10806.70
QPH-FLUX	B/HR-FT2	93411.77	76343.23	76619.83	112657.37	123534.93	71461.16	72917.23	82320.35	71784.36	83015.54
UPH	B/HR-FT2-F	549.67	538.71	381.33	573.80	732.37	454.71	521.36	364.40	587.88	372.20
NUPH		0.33	0.31	0.23	0.33	0.42	0.26	0.30	0.21	0.34	0.22
PRLM		0.0070	0.0071	0.0071	0.0072	0.0071	0.0071	0.0071	0.0073	0.0071	0.0073
REPH		45426.14	46399.88	45919.53	50066.75	48636.17	48279.04	48297.43	50287.62	51745.94	50361.12
PF		319.59	328.95	324.71	358.44	346.72	343.13	343.05	369.10	366.15	368.77
FPH		0.0102	0.0078	0.0106	0.0138	0.0159	0.0163	0.0131	0.0132	0.0134	0.0121
ULI	FT/SEC	5.93	6.08	6.01	6.96	6.72	6.72	6.73	7.17	7.22	7.18

P
1

TEST RUN NO.		5-16IC	5-17C1	5-18C1	7-1C2	7-2C2	7-3C2	7-4C2	8-1C2	8-2C2	8-3C2
PLUG INSERT NO.		3	3	3	5	5	5	5	6	6	6
PLUG INSERT QUALITY SEC											
XPL		0.819	0.448	0.670	0.830	0.826	0.318	0.027	0.452	0.054	0.457
DLPL	FT	3.250	3.000	3.000	3.350	3.450	3.000	3.000	3.000	3.000	3.000
DPPL	PSI	153.000	70.000	110.000	123.000	145.000	22.000	4.000	34.000	13.000	22.000
QX-FLUX	B/HR-FT2	145583.	88892.	131311.	149938.	140149.	62021.	5214.	88632.	10621.	89443.
QXPL	B/HR-FT2-F	1206.408	1274.293	1115.640	1169.231	1183.891	1197.314	380.589	970.775	728.474	1105.057
DTMPL	DEG-F	132.540	69.540	117.700	126.080	118.380	51.800	13.700	91.300	14.580	80.940
U2VPL	FT/SEC	131.316	100.016	160.395	132.367	124.810	43.100	3.324	62.794	6.989	59.215
U2VT	FT/SEC	41.279	22.770	36.516	40.172	43.635	15.068	1.162	21.953	2.444	20.702
REPL		72760.	75423.	75682.	51595.	49525.	50480.	49790.	50785.	50588.	50204.
PHIEG		0.0819	0.1157	0.0826	0.1393	0.2448	0.2642	7.1962	0.2000	5.5334	0.1330
LMPL		7.663E 04	2.207E 04	5.297E 04	5.426E 04	5.938E 04	8.021E 04	7.545E 01	1.647E 04	2.755E 02	1.614E 04
UNPLUGGED TUBE QUAL. SEC											
DX		0.181	0.552	0.330	0.170	0.174	0.682	0.973	0.548	0.946	0.543
XMJPL		0.909	0.724	0.835	0.915	0.913	0.659	0.513	0.726	0.527	0.728
DLUPL	FT	4.850	4.850	3.250	2.750	3.450	8.950	15.750	6.250	12.250	4.250
DPUPL	PSI	10.000	9.000	18.000	5.000	7.000	14.000	19.000	12.000	16.000	8.000
QUPL	B/HR-FT2	21687.964	67807.751	59897.047	37439.409	29466.195	44551.786	36287.937	51597.765	45675.699	75169.142
QMUPL	B/HR-FT2-F	79.835	379.918	247.737	150.868	120.133	297.431	339.875	267.542	415.158	439.380
DTMUPL	DEG-F	271.660	173.480	241.780	248.160	245.240	149.760	106.180	192.860	110.020	171.080
RE		78859.996	80556.817	81381.498	83118.287	80125.203	79426.910	76911.308	79194.765	78382.838	77801.382
PHIEG		0.096	0.132	0.273	0.073	0.097	0.145	0.201	0.143	0.106	0.159
LMUP		2.587E 06	5.835E 05	1.363E 06	3.109E 06	2.913E 06	3.777E 05	1.571E 05	5.703E 05	1.753E 05	5.410E 05

		TEST RUN NO.	5-161C	5-17C1	5-18C1	7-1C2	7-2C2	7-3C2	7-4C2	8-1C2	8-2C2	8-3C2
		PLUG INSERT NO.	3	3	3	5	5	5	5	6	6	6
MEAN QUALITY INCREMENT			0.0265	0.1000	0.1000	0.0290	0.0500	0.1000	0.0135	0.1000	0.0250	0.1000
DX			0.053	0.200	0.200	0.058	0.100	0.200	0.027	0.200	0.050	0.200
DE		FT	0.005	0.007	0.007	0.005	0.005	0.008	0.008	0.008	0.008	0.008
DLX		FT	0.250	1.650	1.350	0.350	0.450	2.350	3.000	2.050	3.000	2.050
DPX		PSI	27.000	40.000	51.000	60.000	89.000	17.000	4.000	24.000	13.000	16.000
PMX		PSI	391.500	308.000	319.500	330.000	342.500	287.500	305.000	290.000	298.500	304.000
QX-FLUX		B/HR-FT2	1.226E 05	7.219E 04	8.720E 04	1.003E 05	1.300E 05	4.977E 04	5.256E 03	5.740E 04	9.857E 03	5.735E 04
UX		B/HR-FT2-F	3800.564	1803.780	1332.374	2018.085	2643.054	1244.239	383.667	867.116	700.036	975.940
DTM		DEG-F	32.260	40.020	63.080	49.700	49.200	40.000	13.700	66.200	14.080	58.760
DTCRX		DEG-F	159.517	79.871	78.551	163.645	267.064	37.963	5.333	38.155	9.956	37.973
DTCR2		DEG-F	1066.113	533.810	524.986	1089.690	1784.884	253.722	35.645	255.002	66.540	253.786
NUOX			0.477	0.598	0.517	0.402	0.597	0.502	0.099	0.418	0.183	0.436
CX2			0.714	1.259	1.483	0.805	0.763	1.673	1.159	1.959	1.171	1.989
BETAX			0.426	0.943	0.959	0.405	0.570	1.051	0.143	1.024	0.268	1.031
REX			3.248E 05	7.569E 04	7.432E 04	3.728E 05	3.575E 05	5.039E 04	4.979E 04	5.060E 04	5.059E 04	5.012E 04
NUX			1739.341	1212.241	923.901	893.840	1163.697	868.614	265.112	604.392	435.348	674.696
KX			36.492	69.519	44.124	56.025	56.619	69.488	203.053	41.992	197.520	47.340
LAMX			1.005E 03	4.348E 03	4.194E 03	1.486E 03	3.819E 03	3.262E 03	7.753E 01	3.256E 03	2.435E 02	3.145E 03
PHIFG			0.168	0.622	1.222	0.128	0.055	0.658	6.993	1.060	6.366	0.735
FG			0.	0.022	0.022	0.	0.	0.032	0.032	0.032	0.032	0.032
PHI			0.	28.254	46.467	0.	0.	20.552	218.526	33.120	198.937	22.981
MEAN QUALITY INCREMENT			0.1265	0.3250	0.3000	0.1290	0.1500	0.2550	0.1135	0.3260	0.1250	0.3320
DX			0.147	0.250	0.200	0.142	0.100	0.110	0.173	0.252	0.150	0.264
DE		FT	0.007	0.007	0.007	0.008	0.008	0.008	0.033	0.008	0.033	0.008
DLX		FT	0.650	1.350	0.800	0.650	0.750	0.650	2.250	0.950	2.450	0.950
DPX		PSI	30.000	30.000	28.000	14.000	14.000	5.000	3.000	10.000	3.000	6.000
PMX		PSI	363.000	273.000	280.000	293.000	291.000	276.500	301.500	273.000	290.500	293.000
QX-FLUX		B/HR-FT2	1.308E 05	1.103E 05	1.472E 05	1.322E 05	7.802E 04	9.896E 04	4.491E 04	1.561E 05	3.621E 04	1.633E 05
UX		B/HR-FT2-F	2005.395	1103.523	1227.274	1527.897	830.208	1320.940	1374.929	1334.666	982.834	1593.000
DTM		DEG-F	65.220	99.940	119.900	86.540	93.980	74.920	32.660	116.940	36.840	102.540
DTCRX		DEG-F	94.172	227.760	210.897	49.718	55.264	98.488	9.266	108.422	10.302	109.006
DTCR2		DEG-F	629.388	1522.204	1409.505	332.287	369.352	591.398	61.931	724.628	68.849	728.530
NUOX			0.669	0.924	0.922	0.631	0.505	0.865	0.265	1.004	0.238	1.080
CX2			1.565	1.464	1.665	2.410	2.131	1.968	2.221	2.394	2.124	2.319
BETAX			1.309	1.692	1.919	1.902	1.346	2.129	0.735	3.007	0.634	3.132
REX			7.139E 04	7.755E 04	7.624E 04	5.190E 04	5.026E 04	5.080E 04	7.648E 04	5.124E 04	7.801E 04	5.049E 04
NUX			1312.868	757.249	838.448	1062.966	578.304	929.576	4173.290	940.308	3003.122	1108.258
KX			42.742	27.791	23.173	32.127	29.581	37.078	95.164	23.751	75.460	27.114
LAMX			5.847E 03	5.292E 04	4.290E 04	5.396E 03	7.099E 03	2.191E 04	5.647E 03	3.825E 04	7.068E 03	3.773E 04
PHIFG			0.911	0.049	0.094	1.119	0.763	0.104	4.593	0.085	3.286	0.052
FG			0.022	0.022	0.022	0.032	0.032	0.032	0.	0.032	0.	0.032
PHI			41.389	2.211	4.281	34.972	23.829	3.245	0.	2.654	0.	1.636

		TEST RUN NO.	5-161C	5-17C1	5-18C1	7-1C2	7-2C2	7-3C2	7-4C2	8-1C2	8-2C2	8-3C2
		PLUG INSERT NO.	3	3	3	5	5	5	5	6	6	6
MEAN QUALITY INCREMENT			0.3000	0.5250	0.5350	0.3000	0.3000	0.3550	0.3000	0.5260	0.3000	0.5320
DX			0.200	0.150	0.270	0.200	0.200	0.090	0.200	0.148	0.200	0.136
DE	FT		0.007	0.033	0.007	0.008	0.008	0.033	0.033	0.033	0.033	0.033
DLX	FT		1.000	0.750	0.850	1.050	0.700	0.350	2.700	0.650	2.800	0.250
DPX	PSI		40.000	2.000	31.000	21.000	13.000	1.000	4.000	2.000	4.000	1.000
PMX	PSI		328.000	257.000	250.500	275.500	277.500	273.500	298.000	267.000	287.000	289.500
QX-FLUX	B/HR-FT2		1.157E 05	1.191E 05	1.870E 05	1.153E 05	1.672E 05	1.504E 05	4.326E 04	1.340E 05	4.224E 04	3.198E 05
UX	B/HR-FT2-F		1011.776	830.259	1052.507	921.256	1330.088	1598.375	651.133	962.875	609.028	2333.011
DTM	DEG-F		114.320	143.460	177.640	125.140	125.700	94.080	66.440	155.260	69.360	137.060
DTCRX	DEG-F		203.491	55.409	529.287	104.409	100.866	24.999	21.789	54.516	22.144	54.248
DTCR2	DEG-F		1360.009	207.700	1984.031	697.804	674.122	167.075	145.622	204.354	147.998	203.348
NUDX			0.791	0.520	1.272	0.793	0.950	0.551	0.309	0.524	0.303	0.842
CX2			1.533	3.483	1.960	2.242	2.503	3.313	2.233	3.664	2.241	4.377
BETAX.			1.516	2.266	3.117	2.223	2.973	2.285	0.863	2.400	0.850	4.609
REX			7.278E 04	8.045E 04	7.793E 04	5.257E 04	5.076E 04	7.805E 04	7.666E 04	7.890E 04	7.821E 04	7.760E 04
NUX			673.466	2591.350	732.692	648.022	934.416	4936.575	1980.274	2676.008	1865.025	7133.165
KX			24.355	19.343	15.615	22.197	22.101	29.522	41.857	17.883	40.073	20.282
LAMX			3.761E 04	1.906E 05	1.996E 05	3.219E 04	3.116E 04	6.517E 04	4.147E 04	1.843E 05	4.312E 04	1.788E 05
PHIFG			0.127	0.359	0.028	0.182	0.182	0.922	0.723	0.437	0.658	0.598
FG			0.022	0.	0.022	0.032	0.032	0.	0.	0.	0.	0.
PHI			5.789	0.	1.270	5.681	5.679	0.	0.	0.	0.	0.
MEAN QUALITY INCREMENT			0.5000	0.7000	0.7350	0.5000	0.5000	0.5000	0.5000	0.7000	0.5000	0.7000
DX			0.200	0.200	0.130	0.200	0.200	0.200	0.200	0.200	0.200	0.200
DE	FT		0.007	0.033	0.033	0.008	0.008	0.033	0.033	0.033	0.033	0.033
DLX	FT		0.500	1.100	0.650	0.550	0.550	1.200	2.800	1.250	1.900	0.900
DPX	PSI		24.000	2.000	2.000	12.000	11.000	2.000	3.000	2.000	2.500	1.000
PMX	PSI		296.000	255.000	234.000	259.000	265.500	272.000	294.500	265.000	283.750	288.500
QX-FLUX	B/HR-FT2		2.313E 05	1.083E 05	1.177E 05	2.201E 05	2.128E 05	9.747E 04	4.172E 04	9.414E 04	6.225E 04	1.306E 05
UX	B/HR-FT2-F		1386.221	622.662	533.830	1313.822	1294.815	817.937	405.169	505.591	588.947	792.705
DTM	DEG-F		166.880	173.900	220.520	167.520	164.340	119.160	102.960	186.200	105.700	164.760
DTCRX	DEG-F		494.160	58.777	57.944	252.247	243.090	52.778	52.283	57.775	53.138	57.171
DTCR2	DEG-F		1852.358	220.325	217.204	945.549	911.221	197.837	195.982	216.570	199.189	214.306
NUDX			1.310	0.563	0.562	1.323	1.301	0.489	0.334	0.501	0.409	0.607
CX2			1.996	3.874	4.390	2.812	2.814	3.154	2.435	3.811	2.705	3.969
BETAX			3.269	2.729	3.087	4.651	4.578	1.930	1.018	2.385	1.383	3.014
REX			7.415E 04	8.057E 04	8.089E 04	5.322E 04	5.121E 04	7.814E 04	7.686E 04	7.902E 04	7.840E 04	7.766E 04
NUX			937.568	1945.904	1691.065	933.911	916.589	2528.599	1234.928	1569.973	1807.219	2425.212
KX			16.663	15.955	12.567	16.567	16.893	23.307	27.006	14.910	26.291	16.869
LAMX			1.424E 05	5.098E 05	6.650E 05	1.186E 05	1.133E 05	1.564E 05	1.470E 05	4.899E 05	1.528E 05	4.584E 05
PHIFG			0.050	0.137	0.200	0.068	0.068	0.270	0.186	0.128	0.216	0.096
FG			0.022	0.	0.	0.032	0.032	0.	0.	0.	0.	0.
PHI			2.295	0.	0.	2.111	2.116	0.	0.	0.	0.	0.

D-F

TEST RUN NO.		5-161C	5-17C1	5-18C1	7-1C2	7-2C2	7-3C2	7-4C2	8-1C2	8-2C2	8-3C2
PLUG INSERT NO.		3	3	3	5	5	5	5	6	6	6
MEAN QUALITY INCREMENT		0.7150	0.9000	0.9000	0.7150	0.7150	0.7000	0.7000	0.9000	0.7000	0.9000
DX		0.230	0.200	0.200	0.230	0.230	0.200	0.200	0.200	0.200	0.200
DE	FT	0.007	0.033	0.033	0.008	0.008	0.033	0.033	0.033	0.033	0.033
DLX	FT	0.850	3.000	2.600	0.750	1.000	1.800	2.800	4.350	2.000	3.100
DPX	PSI	32.000	5.000	16.000	16.000	18.000	8.000	8.000	8.000	2.500	6.000
PMX	PSI	268.000	251.500	225.000	246.000	251.000	269.500	291.500	260.000	281.250	255.000
QX-FLUX	B/HR-FT2	1.505E 05	3.971E 04	4.508E 04	1.856E 05	1.346E 05	6.498E 04	4.172E 04	2.705E 04	5.914E 04	3.792E 04
UX	B/HR-FT2-F	703.198	193.495	179.315	883.439	652.461	419.314	299.858	120.876	417.944	193.757
DTM	DEG-F	222.540	208.420	252.500	210.100	206.280	154.960	139.120	223.300	141.500	198.800
DTCRX	DEG-F	539.888	43.716	43.757	274.508	264.491	57.302	56.762	42.997	57.686	42.499
DTCR2	DEG-F	2123.769	163.871	164.022	1028.992	991.444	214.796	212.771	161.175	214.236	159.306
NUDX		1.271	0.427	0.429	1.454	1.238	0.453	0.372	0.335	0.445	0.407
CX2		2.172	4.279	4.724	3.165	2.949	3.321	2.865	3.965	3.135	4.142
BETAX.		3.453	2.282	2.537	5.755	4.566	1.881	1.333	1.664	1.745	2.110
REX		7.569E 04	8.073E 04	8.144E 04	5.379E 04	5.177E 04	7.828E 04	7.702E 04	7.931E 04	7.954E 04	7.786E 04
NUX		484.076	595.663	571.376	633.554	466.178	1298.341	915.664	376.546	1284.509	584.890
KX		12.477	13.310	10.969	13.199	13.448	17.920	19.993	12.401	19.637	13.980
LAMX		5.140E 05	2.430E 06	2.604E 06	4.138E 05	3.953E 05	4.812E 05	4.525E 05	2.345E 06	4.698E 05	2.182E 06
PHIFG		0.018	0.075	0.259	0.031	0.028	0.137	0.094	0.087	0.104	0.100
FG		0.022	0.	0.	0.032	0.032	0.	0.	0.	0.	0.
PHI		0.305	0.	0.	0.061	0.886	0.	0.	0.	0.	0.

MEAN QUALITY INCREMENT		0.9150	0.	0.	0.9150	0.9150	0.9000	0.9000	0.	0.9000	0.
DX		0.170	0.	0.	0.170	0.170	0.200	0.200	0.	0.200	0.
DE	FT	0.033	0.	0.	0.033	0.033	0.033	0.033	0.	0.033	0.
DLX	FT	4.850	0.	0.	2.750	3.450	5.600	5.200	0.	3.100	0.
DPX	PSI	10.000	0.	0.	5.000	7.000	8.000	6.000	0.	4.000	0.
PMX	PSI	247.000	0.	0.	234.500	238.500	264.000	287.000	0.	279.000	0.
QX-FLUX	B/HR-FT2	2.027E 04	0.	0.	3.742E 04	2.883E 04	2.089E 04	2.245E 04	0.	3.815E 04	0.
UX	B/HR-FT2-F	74.621	0.	0.	150.772	117.558	108.260	127.368	0.	214.543	0.
DTM	DEG-F	271.660	0.	0.	248.160	245.280	192.920	176.360	0.	177.840	0.
DTCRX	DEG-F	39.947	0.	0.	41.989	40.535	42.651	42.209	0.	42.881	0.
DTCR2	DEG-F	149.742	0.	0.	157.395	151.944	159.878	158.221	0.	160.740	0.
NUDX		0.278	0.	0.	0.403	0.354	0.316	0.332	0.	0.436	0.
CX2		4.129	0.	0.	4.629	4.390	3.586	3.534	0.	4.035	0.
BETAX		1.438	0.	0.	2.332	1.942	1.416	1.468	0.	2.200	0.
REX		7.981E 04	0.	0.	8.312E 04	8.013E 04	7.860E 04	7.728E 04	0.	7.873E 04	0.
NUX		234.402	0.	0.	477.460	371.313	336.384	390.038	0.	660.729	0.
KX		10.209	0.	0.	11.168	11.301	14.390	15.760	0.	15.622	0.
LAMX		2.921E 06	0.	0.	3.140E 06	3.022E 06	2.306E 06	2.160E 06	0.	2.236E 06	0.
PHIFG		0.093	0.	0.	0.072	0.087	0.070	0.061	0.	0.064	0.
FG		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
PHI		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

TEST RUN NO.		8-4C2	8-5C2	8-7C2	8-11C2	8-12C2	8-13C2	8-14C2	8-15C2	8-16C2	8-17C2
PLUG INSERT NO.		6	6	6	6	6	6	6	6	6	6
------- TEST DATA --------											
WN	LB/HR	1770.00	1770.00	1950.00	2070.00	2055.00	2055.00	2055.00	2055.00	2055.00	2070.00
TNBI	DEG-F	1295.00	1328.00	1280.00	1275.00	1265.00	1335.00	1258.00	1328.00	1260.00	1325.00
TNBO	DEG-F	1085.00	1112.00	1085.00	1080.00	1075.00	1155.00	1076.00	1135.00	1080.00	1126.00
DELTN	DEG-F	210.00	216.00	185.00	195.00	190.00	180.00	182.00	193.00	180.00	199.00
WH	LB/HR	483.00	507.00	499.00	522.00	492.00	486.00	497.00	512.00	496.00	493.00
THBI	DEG-F	520.00	520.00	516.00	435.00	435.00	435.00	428.00	438.00	435.00	435.00
THBO	DEG-F	1225.00	1250.00	1210.00	1210.00	1195.00	1250.00	1193.00	1250.00	1195.00	1250.00
PHBI	PSIA	483.00	420.00	401.00	395.00	373.00	458.00	371.00	446.00	369.00	451.00
P1	PSIA	306.00	325.00	310.00	325.00	301.00	326.00	304.00	334.00	302.00	335.00
P2	PSIA	291.00	309.00	300.00	316.00	292.00	270.00	293.00	299.00	293.00	295.00
PHBO	PSIA	210.00	224.00	210.00	220.00	201.00	186.00	203.00	204.00	201.00	200.00
------ HEAT BALANCE ------											
QN	BTU/HR	78057.00	80287.20	75757.50	84766.50	81994.50	77679.00	78542.10	83289.15	77679.00	86505.30
QHG	BTU/HR	72075.67	73866.90	72274.76	76974.59	72376.36	71281.68	73199.03	75970.91	72964.78	73201.87
QHLI	KW	2.34	1.88	1.02	2.28	2.32	1.87	1.57	2.14	1.38	3.90
WNNET	LB/HR	1589.02	1628.46	1860.35	1879.72	1813.94	1885.76	1915.20	1874.44	1930.29	1751.66
----- PREHEAT SECTION ----											
DEPH	FT	0.0049	0.0049	0.0049	0.0049	0.0049	0.0049	0.0049	0.0049	0.0049	0.0049
DLPHC	FT	1.25	1.25	1.25	1.25	1.25	0.90	1.25	0.90	1.25	1.00
DPPH	PSI	177.00	95.00	91.00	70.00	72.00	55.00	67.00	55.00	67.00	61.00
PCC	PSIA	306.00	325.00	310.00	325.00	301.00	403.00	304.00	391.00	302.00	390.00
TNCC	DEG-F	1112.00	1140.00	1108.00	1109.00	1103.00	1181.00	1103.00	1163.00	1106.00	1155.00
TSCO	DEG-F	1095.36	1106.00	1097.60	1106.00	1092.56	1149.44	1094.24	1142.96	1093.12	1142.40
DLTA00	DEG-F	16.64	34.00	10.40	3.00	10.44	31.56	8.76	20.04	12.88	12.60
QPHC	BTU/HR	9231.71	9655.81	9432.10	11393.52	10514.38	11145.26	10761.44	11730.53	10608.89	11334.32
QPH-FLUX	B/HR-FT2	68997.27	73765.05	72055.98	86963.72	80324.05	118255.02	82211.43	124464.94	81046.05	108234.84
UPH	B/HR-FT2-F	443.53	377.70	516.24	727.49	525.13	537.19	553.49	652.52	501.77	638.69
NUPH		0.25	0.21	0.29	0.42	0.30	0.31	0.32	0.38	0.29	0.37
PRLM		0.0071	0.0071	0.0071	0.0073	0.0073	0.0073	0.0073	0.0073	0.0073	0.0073
REPHM		49692.90	52251.05	51324.59	52746.07	49540.34	49060.18	49974.43	52282.67	49950.41	50295.11
PE		351.57	368.59	363.29	384.23	362.93	357.30	366.94	379.56	365.85	365.51
FPH		0.0109	0.0122	0.0121	0.0088	0.0101	0.0143	0.0093	0.0107	0.0093	0.0131
ULI	FT/SEC	6.93	7.28	7.16	7.50	7.06	6.99	7.13	7.36	7.12	7.09

TEST RUN NO.		8-4C2	8-5C2	8-7C2	8-11C2	8-12C2	8-13C2	8-14C2	8-15C2	8-16C2	8-17C2
PLUG INSERT NO.		6	6	6	6	6	6	6	6	6	6
PLUG INSERT QUALITY SEC											
XPL		0.303	0.355	0.209	0.069	0.147	0.828	0.179	0.635	0.165	0.780
DLPL	FT	3.000	3.000	3.000	3.000	3.000	3.350	3.000	3.350	3.000	3.250
DPPL	PSI	15.000	16.000	10.000	9.000	9.000	133.000	11.000	92.000	9.000	95.000
QX-FLUX	B/HR-FT2	57274.	70475.	40847.	14058.	28408.	133490.	34918.	113969.	32074.	138944.
UMPL	B/HR-FT2-F	1191.227	992.881	1352.543	1275.689	1135.417	1064.395	1365.354	1177.364	1133.341	1339.868
DTMPL	DEG-F	48.080	70.980	30.200	11.020	25.020	130.560	25.580	96.800	28.300	103.700
U2VPL	FT/SEC	37.801	44.166	26.268	8.638	18.693	109.701	22.910	82.117	21.043	98.250
U2VT	FT/SEC	13.216	15.441	9.184	3.020	6.535	38.353	8.010	28.709	7.357	34.349
REPL		48577.	50451.	49990.	51842.	49554.	47249.	49385.	50163.	49921.	48368.
PHIEG		0.2196	0.1629	0.2931	2.3246	0.5329	0.2622	0.4332	0.2772	0.4189	0.2096
LMPL		6.854E 03	9.349E 03	3.366E 03	4.213E 02	1.753E 03	5.506E 04	2.548E 03	3.027E 04	2.179E 03	4.783E 04
UNPLUGGED TUBE QUAL. SEC											
DX		0.697	0.645	0.791	0.931	0.853	0.172	0.821	0.365	0.835	0.220
XMUPL		0.651	0.578	0.604	0.534	0.574	0.914	0.590	0.817	0.583	0.890
DLUPL	FT	9.250	6.450	8.050	14.250	11.250	2.550	8.050	3.250	8.750	2.250
DPUPL	PSI	14.000	11.000	13.000	81.000	18.000	4.000	13.000	6.000	15.000	4.000
QUPL	B/HR-FT2	42814.196	59556.543	57625.489	40962.983	43842.083	38040.035	59569.368	67596.632	55645.429	56710.364
UMUPL	B/HR-FT2-F	290.226	351.283	433.876	330.716	385.459	152.907	540.459	329.933	494.840	263.722
DTMUPL	DEG-F	147.520	169.540	116.680	121.140	113.740	249.040	110.220	204.880	112.440	215.040
EE		75266.224	77934.686	77220.811	81854.545	75725.042	75684.016	77305.933	79088.388	77206.979	76320.131
PHIEG		0.161	0.161	0.192	0.748	0.211	0.081	0.199	0.115	0.217	0.100
LAMUP		3.271E 05	3.872E 05	2.602E 05	1.925E 05	2.233E 05	2.617E 06	2.434E 05	9.847E 05	2.343E 05	1.860E 06

		TEST RUN NO.	8-4C2	8-5C2	8-7C2	8-11C2	8-12C2	8-13C2	8-14C2	8-15C2	8-16C2	8-17C2
		PLUG INSERT NO.	6	6	6	6	6	6	6	5	5	6
MEAN QUALITY INCREMENT			0.1000	0.1000	0.1060	0.0345	0.0730	0.0700	0.0895	0.0219	0.0825	0.0217
DX			0.200	0.200	0.212	0.069	0.146	0.140	0.179	0.044	0.165	0.043
DE		FT	0.008	0.008	0.008	0.008	0.008	0.005	0.008	0.005	0.008	0.005
DLX		FT	2.450	2.450	3.000	3.000	3.000	0.350	3.000	0.350	3.000	0.250
DPX		PSI	12.000	14.000	10.000	9.000	9.000	77.000	11.000	57.000	9.000	55.000
PMX		PSI	300.000	313.000	305.000	320.500	295.500	364.500	299.500	362.500	297.500	362.500
QX-FLUX		B/HR-FT2	4.636E 04	4.862E 04	4.144E 04	1.410E 04	2.815E 04	2.258E 05	3.486E 04	7.527E 04	3.211E 04	1.008E 05
UX		B/HR-FT2-F	1219.879	869.411	1372.210	1279.550	1125.145	5561.971	1362.881	1905.608	1134.642	3194.216
DTM		DEG-F	38.000	55.920	30.200	11.020	25.020	63.380	25.580	39.500	28.300	31.500
DTCRX		DEG-F	36.721	38.317	40.026	14.076	27.747	375.537	34.033	128.927	31.439	123.524
DTCR2		DEG-F	245.421	255.087	267.508	94.075	185.445	2509.856	227.454	861.670	210.120	822.218
NUDX			0.489	0.406	0.532	0.265	0.401	0.804	0.489	0.327	0.429	0.422
CX2			1.637	1.770	1.458	1.086	1.384	0.847	1.395	0.728	1.429	0.756
BETAX			1.002	0.899	0.971	0.387	0.695	0.852	0.854	0.298	0.765	0.389
REX			4.852E 04	5.042E 04	4.999E 04	5.184E 04	4.955E 04	3.603E 05	4.998E 04	3.848E 05	4.992E 04	3.705E 05
NUX			844.974	597.035	944.190	877.585	781.058	1546.273	944.910	828.014	787.159	1390.106
KX			73.192	49.771	92.113	252.582	111.143	43.985	108.721	70.572	98.266	86.495
LAMX			3.084E 03	3.086E 03	3.504E 03	4.307E 02	1.741E 03	6.892E 03	2.565E 03	8.596E 02	2.200E 03	8.202E 02
PHIFG			0.490	0.542	0.291	2.273	0.537	0.031	0.430	0.207	0.415	0.307
FG			0.032	0.032	0.032	0.032	0.032	0.	0.032	0.	0.032	0.
PHI			15.311	16.943	8.790	71.029	16.781	0.	13.453	0.	12.967	0.
MEAN QUALITY INCREMENT			0.2500	0.2805	0.3060	0.1345	0.2730	0.1700	0.2895	0.1219	0.2825	0.1217
DX			0.100	0.161	0.188	0.131	0.254	0.060	0.221	0.156	0.235	0.156
DE		FT	0.008	0.008	0.033	0.033	0.033	0.008	0.033	0.008	0.033	0.008
DLX		FT	0.550	0.550	2.950	2.850	3.150	0.450	1.750	1.250	3.150	0.900
DPX		PSI	3.000	3.000	4.000	69.000	6.000	8.000	3.000	15.000	5.000	8.000
PMX		PSI	292.500	310.000	298.000	281.500	289.000	322.000	291.500	326.500	290.500	331.000
QX-FLUX		B/HR-FT2	1.032E 05	1.746E 05	3.737E 04	2.819E 04	4.664E 04	7.525E 04	7.379E 04	7.516E 04	4.347E 04	1.007E 05
UX		B/HR-FT2-F	1466.565	1878.949	562.496	543.801	753.280	736.471	1207.251	993.412	686.224	1534.292
DTM		DEG-F	72.400	92.900	66.440	51.820	61.920	102.180	61.120	75.660	63.340	65.640
DTCRX		DEG-F	84.034	96.420	22.218	11.483	20.071	59.082	21.234	46.377	20.789	44.475
DTCR2		DEG-F	561.631	644.409	148.492	76.742	134.142	394.867	141.917	309.955	138.940	297.243
NUDX			0.883	1.046	0.291	0.187	0.319	0.491	0.416	0.476	0.310	0.587
CX2			1.910	2.309	2.144	2.110	2.281	2.119	2.516	2.026	2.234	2.142
BETAX			2.184	3.020	0.779	0.492	0.909	1.301	1.309	1.206	0.865	1.573
REX			4.879E 04	5.065E 04	7.697E 04	8.149E 04	7.639E 04	4.763E 04	7.702E 04	5.068E 04	7.692E 04	4.868E 04
NUX			1020.616	1295.212	1710.703	1671.056	2303.870	504.748	3686.534	679.379	2096.810	1047.023
KX			39.492	29.950	41.857	53.621	44.892	27.242	45.486	36.797	43.889	42.421
LAMX			1.964E 04	2.517E 04	4.349E 04	8.608E 03	3.424E 04	8.236E 03	3.899E 04	4.455E 03	3.698E 04	4.259E 03
PHIFG			0.085	0.043	0.631	50.651	1.115	0.659	0.881	0.770	0.858	0.625
FG			0.032	0.032	0.	0.	0.	0.032	0.	0.032	0.	0.032
PHI			2.666	1.342	0.	0.	0.	20.593	0.	24.057	0.	19.537

TEST RUN NO. / PLUG INSERT NO.		8-4C2 6	8-5C2 6	8-7C2 6	8-11C2 6	8-12C2 6	8-13C2 6	8-14C2 6	8-15C2 6	8-16C2 6	8-17C2 6
MEAN QUALITY INCREMENT		0.3500	0.4805	0.5000	0.3000	0.5000	0.3000	0.5000	0.3000	0.5000	0.3000
DX	FT	0.100	0.239	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200
DE	FT	0.033	0.033	0.033	0.033	0.033	0.008	0.033	0.008	0.033	0.008
DLX	PSI	0.400	0.950	1.500	2.900	2.500	1.000	1.700	1.000	1.700	1.050
DPX	PSI	1.000	2.000	3.000	3.000	3.000	18.000	3.000	11.000	3.000	18.000
PMX	B/HR-FT2	290.500	308.000	294.500	245.500	284.500	309.000	288.500	313.500	286.500	318.000
QX-FLUX	B/HR-FT2-F	1.420E 05	1.497E 05	7.819E 04	4.228E 04	4.628E 04	1.129E 05	6.874E 04	1.203E 05	6.860E 04	1.103E 05
UX	DEG-F	1589.025	1142.619	786.146	403.674	457.452	875.301	721.450	1079.477	694.916	1077.112
DTM	DEG-F	89.340	131.220	99.460	104.740	101.160	128.960	95.280	111.440	98.720	102.420
DTCRX	DEG-F	23.872	52.031	52.493	23.460	51.960	96.323	52.403	102.630	52.340	98.578
DTCR2		159.547	195.037	196.770	156.794	194.773	643.764	196.434	685.915	196.196	658.834
NUDX		0.533	0.539	0.466	0.262	0.360	0.742	0.450	0.821	0.442	0.816
CX2		3.249	3.496	2.819	2.486	2.511	2.293	2.713	2.172	2.741	2.117
BETAX		2.166	2.357	1.642	0.813	1.130	2.129	1.525	2.230	1.516	2.159
PEX		7.491E 04	7.774E 04	7.716E 04	8.371E 04	7.664E 04	4.798E 04	7.719E 04	5.105E 04	7.715E 04	4.903E 04
NUX		4855.385	3457.277	2396.119	1269.269	1403.057	603.661	2207.211	742.863	2128.708	739.629
KX		31.117	21.224	27.956	26.476	27.472	21.575	29.174	24.971	28.154	27.174
LAMX		5.877E 04	1.299E 05	1.474E 05	5.021E 04	1.498E 05	2.800E 04	1.494E 05	2.922E 04	1.499E 05	2.803E 04
PHIFG		0.928	0.395	0.345	0.385	0.206	0.207	0.301	0.112	0.301	0.191
FG		0.	0.	0.	0.	0.	0.032	0.	0.032	0.	0.032
PHI		0.	0.	0.	0.	0.	6.464	0.	3.508	0.	5.973
MEAN QUALITY INCREMENT		0.5000	0.7000	0.7000	0.5000	0.7000	0.5000	0.7000	0.5150	0.7000	0.5000
DX	FT	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.230	0.200	0.200
DE	FT	0.033	0.033	0.033	0.033	0.033	0.008	0.033	0.008	0.033	0.008
DLX	PSI	1.250	1.300	1.400	1.600	2.400	0.650	1.700	0.750	1.000	0.650
DPX	PSI	2.000	2.000	2.000	2.000	4.000	12.000	3.000	9.000	2.000	9.000
PMX	B/HR-FT2	249.000	306.000	292.000	243.000	281.000	294.000	285.500	303.500	284.000	304.500
QX-FLUX	B/HR-FT2-F	9.086E 04	9.163E 04	8.378E 04	7.663E 04	4.820E 04	1.737E 05	6.874E 04	1.845E 05	1.166E 05	1.782E 05
UX	DEG-F	777.084	530.730	631.027	551.165	355.277	1031.724	539.389	1213.202	890.121	1246.368
DTM	DEG-F	116.920	172.640	132.760	139.040	135.680	168.320	127.440	152.040	131.020	142.980
DTCRX	DEG-F	50.917	57.631	56.979	55.308	56.430	231.887	56.897	250.134	56.817	237.363
DTCR2		190.863	216.030	213.586	211.070	211.530	969.226	213.277	937.623	212.980	889.754
NUDX		0.466	0.487	0.539	0.419	0.411	1.118	0.503	1.224	0.647	1.215
CX2		3.105	3.624	3.363	3.052	2.981	2.703	3.184	2.587	3.665	2.566
BETAX		1.811	2.206	2.268	1.599	1.530	3.780	2.002	3.959	2.966	3.898
PEX		7.499E 04	7.783E 04	7.731E 04	8.387E 04	7.684E 04	4.843E 04	7.736E 04	5.134E 04	7.729E 04	4.940E 04
NUX		2376.673	1607.407	1926.338	1735.824	1092.081	717.327	1653.327	838.925	2730.961	861.442
KX		23.775	16.114	20.941	19.942	20.479	16.519	21.808	18.296	21.211	19.456
LAMX		1.458E 05	4.441E 05	4.533E 05	1.777E 05	4.619E 05	1.017E 05	4.599E 05	1.138E 05	4.611E 05	1.013E 05
PHIFG		0.290	0.135	0.125	0.166	0.145	0.073	0.152	0.041	0.172	0.054
FG		0.	0.	0.	0.	0.	0.032	0.	0.032	0.	0.032
PHI		0.	0.	0.	0.	0.	2.295	0.	1.269	0.	1.679

TEST RUN NO.		8-4C2	8-5C2	8-7C2	8-11C2	8-12C2	8-13C2	8-14C2	8-15C2	8-16C2	8-17C2
PLUG INSERT NO.		6	6	6	6	6	6	6	6	6	6
MEAN QUALITY INCREMENT		0.7000	0.9000	0.9000	0.7000	0.9000	0.7150	0.9000	0.7150	0.9000	0.6900
DX		0.200	0.200	0.200	0.200	0.200	0.230	0.200	0.170	0.200	0.180
DE	FT	0.033	0.033	0.033	0.033	0.033	0.008	0.033	0.033	0.033	0.008
DLX	FT	1.750	4.200	2.200	2.000	3.200	0.900	2.900	0.250	2.900	0.400
DPX	PSI	2.000	7.000	4.000	2.000	5.000	18.000	4.000	2.000	5.000	5.000
PMX	PSI	297.000	301.500	289.000	241.000	276.500	279.000	282.000	298.000	240.500	297.500
QX-FLUX	B/HR-FT2	6.490E 04	2.835E 04	5.331E 04	6.131E 04	3.615E 04	1.442E 05	4.030E 04	4.090E 05	4.022E 04	2.630E 05
QX	B/HR-FT2-F	421.430	134.397	320.343	354.418	212.141	688.155	251.125	2182.083	245.154	1457.639
DTM	DEG-F	154.360	211.160	166.420	172.380	170.420	211.120	160.460	187.440	164.040	178.800
DTCRX	DEG-F	55.260	42.831	42.345	61.129	41.971	251.876	42.296	58.075	42.238	258.463
DTCR2	DEG-F	217.144	160.551	158.731	220.140	157.329	944.155	158.548	217.594	158.330	958.847
NUOX		0.443	0.335	0.525	0.434	0.434	1.218	0.469	1.015	0.465	1.683
CX2		3.338	3.856	4.311	3.325	3.985	3.032	4.004	5.430	4.031	3.238
BETAX		1.849	1.615	2.832	1.805	2.166	4.619	2.350	6.889	2.342	6.815
REX		7.510E 04	7.802E 04	7.748E 04	5.400E 04	7.709E 04	4.897E 04	7.756E 04	7.597E 04	7.749E 04	4.952E 04
NUX		1287.481	407.658	978.752	1117.538	653.952	479.498	771.446	6636.311	753.913	1011.238
KX		18.006	13.172	16.703	16.027	16.300	13.160	17.317	14.837	16.938	15.553
LAMX		4.477E 05	2.114E 06	2.155E 06	5.461E 05	2.206E 06	3.538E 05	2.190E 06	4.981E 05	2.196E 06	2.964E 05
PHIEG		0.105	0.088	0.095	0.067	0.081	0.037	0.071	0.648	0.089	0.025
EG		0.	0.	0.	0.	0.	0.032	0.	0.	0.	0.032
PHI		0.	0.	0.	0.	0.	1.160	0.	0.	0.	0.782
MEAN QUALITY INCREMENT		0.9000	0.	0.	0.9000	0.	0.9150	0.	0.9000	0.	0.8900
DX		0.200	0.	0.	0.200	0.	0.170	0.	0.200	0.	0.220
DE	FT	0.033	0.	0.	0.033	0.	0.033	0.	0.033	0.	0.033
DLX	FT	5.850	0.	0.	4.900	0.	2.550	0.	3.000	0.	2.250
DPX	PSI	9.000	0.	0.	5.000	0.	4.000	0.	4.000	0.	4.000
PMX	PSI	281.500	0.	0.	237.500	0.	268.000	0.	295.000	0.	293.000
QX-FLUX	B/HR-FT2	1.941E 04	0.	0.	2.502E 04	0.	3.763E 04	0.	4.010E 04	0.	5.663E 04
QX	B/HR-FT2-F	100.164	0.	0.	120.305	0.	151.085	0.	183.435	0.	253.345
DTM	DEG-F	193.820	0.	0.	208.000	0.	249.040	0.	218.600	0.	215.040
DTCRX	DEG-F	41.114	0.	0.	45.438	0.	38.534	0.	43.349	0.	43.324
DTCR2	DEG-F	154.115	0.	0.	170.326	0.	144.444	0.	162.494	0.	162.399
NUOX		0.297	0.	0.	0.346	0.	0.384	0.	0.394	0.	0.464
CX2		3.548	0.	0.	3.776	0.	4.729	0.	4.232	0.	4.552
BETAX		1.316	0.	0.	1.633	0.	2.273	0.	2.087	0.	2.640
REX		7.540E 04	0.	0.	8.422E 04	0.	7.569E 04	0.	7.915E 04	0.	7.632E 04
NUX		307.796	0.	0.	380.235	0.	468.259	0.	558.924	0.	803.413
KX		14.336	0.	0.	13.326	0.	11.149	0.	12.720	0.	12.929
LAMX		2.143E 06	0.	0.	2.601E 06	0.	2.686E 06	0.	2.165E 06	0.	1.881E 06
PHIEG		0.084	0.	0.	0.041	0.	0.080	0.	0.068	0.	0.099
EG		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
PHI		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

		TEST RUN NO.	10-2C1	10-3	10-4C1	10-5	10-6	10-7	10-8	10-9
		PLUG INSERT NO.	7	7	7	7	7	7	7	7
------- TEST DATA --------										
WN	LB/HR		2040.00	2040.00	2040.00	2050.00	2040.00	2040.00	2040.00	2040.00
TN8I	DEG-F		1270.00	1320.00	1270.00	1315.00	1290.00	1330.00	1275.00	1325.00
TN8O	DEG-F		1110.00	1160.00	1090.00	1130.00	1110.00	1145.00	1090.00	1115.00
DELTN	DEG-F		160.00	160.00	180.00	185.00	180.00	185.00	185.00	210.00
WH	LB/HR		462.00	462.00	511.00	517.00	504.00	517.00	520.00	590.00
TH8I	DEG-F		440.00	440.00	445.00	445.00	445.00	445.00	500.00	500.00
TH8O	DEG-F		1200.00	1245.00	1200.00	1245.00	1220.00	1255.00	1210.00	1260.00
PH8I	PSIA		346.00	389.00	343.00	387.00	362.00	391.00	344.00	393.00
PI	PSIA		308.00	305.00	302.00	316.00	299.00	314.00	299.00	339.00
P2	PSIA		297.00	237.00	291.00	336.00	289.00	291.00	292.00	332.00
PH8O	PSIA		212.00	216.00	190.00	212.00	207.00	198.00	195.00	223.00
------ HEAT BALANCE ------										
QN	BTU/HR		68544.00	68544.00	77112.00	79642.50	77112.00	79254.00	79254.00	89964.00
QHG	BTU/HR		67940.35	66976.33	75070.50	76525.13	74289.57	76663.60	75596.30	86491.14
QHL1	KW		0.18	0.46	0.60	0.91	0.83	0.76	1.07	1.02
WNNET	LB/HR		2022.03	1993.34	1985.99	1969.78	1965.33	1973.32	1945.85	1961.25
----- PREHEAT SECTION ----										
DEPH	FT		0.0058	0.0058	0.0058	0.0058	0.0058	0.0058	0.0058	0.0058
DLPHC	FT		1.25	0.70	1.70	0.90	1.00	0.75	1.25	1.25
DPPH	PSI		38.00	16.00	33.00	34.00	30.00	22.00	45.00	54.00
P8O	PSIA		308.00	373.00	330.00	353.00	332.00	369.00	299.00	339.00
TH8O	DEG-F		1133.00	1183.00	1116.00	1157.00	1136.00	1171.00	1114.00	1144.00
TSO	DEG-F		1095.48	1132.88	1092.00	1121.68	1109.92	1130.64	1091.28	1113.84
DLTAO	DEG-F		37.52	50.12	24.00	35.32	26.08	40.36	22.72	30.16
QPHC	BTU/HR		9357.05	10178.41	10745.05	11369.92	10891.39	11520.47	9992.63	11770.38
QPH-FLUX	B/HR-FT2		75332.36	138852.45	60357.52	120638.65	104005.20	146583.25	76338.15	89919.17
UPH	B/HR-FT2-F		345.95	552.37	319.83	553.56	527.19	634.47	438.27	463.57
MUPH			0.24	0.38	0.22	0.37	0.36	0.43	0.30	0.31
PRLM			0.0073	0.0073	0.0073	0.0073	0.0073	0.0073	0.0071	0.0071
REPHM			34427.78	34006.33	38084.39	39833.05	37739.59	38724.99	39313.34	44807.92
PE			251.27	248.37	277.77	282.29	275.46	283.09	280.34	317.14
EPH			0.0257	0.0341	0.0234	0.0277	0.0289	0.0254	0.0237	0.0219
UL1	FT/SEC		4.15	4.06	4.59	4.65	4.53	4.65	4.67	5.31

TEST RUN NO.		10-2C1	10-3	10-4C1	10-5	10-6	10-7	10-8	10-9
PLUG INSERT NO.		7	7	7	7	7	7	7	7
PLUG INSERT QUALITY SEC									
XPL		0.215	0.805	0.088	0.315	0.309	0.661	0.176	0.218
DLPL	FT	2.000	2.550	1.550	2.350	2.250	2.500	2.000	2.000
DPPL	PSI	11.000	86.000	9.000	47.000	43.000	78.000	7.000	7.000
QX-FLUX	B/HR-FT2	58409.	167802.	33958.	81317.	81233.	160617.	53750.	75532.
UMPL	B/HR-FT2-F	1079.654	1314.029	1006.454	1121.928	1329.079	1418.875	1369.780	1477.546
DTMPL	DEG-F	54.100	127.700	33.740	72.480	61.120	113.200	39.240	51.120
U2VPL	FT/SEC	24.759	93.418	11.355	39.479	39.661	86.646	23.121	29.063
U2VT	FT/SEC	8.936	33.304	4.048	14.075	14.139	30.890	8.243	10.361
REPL		46349.	44653.	51505.	51089.	50335.	51075.	52412.	58109.
PHIEG		0.5603	0.2768	2.8567	0.8208	0.8147	0.2906	0.4128	0.2331
LMPL		3.369E 03	4.969E 04	6.886E 02	7.234E 03	7.139E 03	3.459E 04	2.565E 03	3.88CE 03
UNPLUGGED TUBE QUAL. SEC									
DX		0.785	0.195	0.912	0.685	0.692	0.339	0.824	0.782
XMUPL		0.608	0.903	0.544	0.657	0.654	0.830	0.588	0.609
DLUPL	FT	6.250	3.750	11.250	6.250	5.850	2.650	9.250	8.750
DPUPL	PSI	9.000	5.000	19.000	7.000	9.000	5.000	17.000	17.000
QUPL	B/HR-FT2	68102.839	27598.249	48727.931	66611.359	70059.309	77780.144	54472.249	61874.747
UMUPL	B/HR-FT2-F	533.173	124.227	408.380	405.219	457.426	361.339	431.020	424.265
DTMUPL	DEG-F	127.900	222.160	119.320	164.100	153.160	215.280	126.380	145.840
RE		71547.194	70409.620	79775.939	79516.559	78509.842	80299.119	81061.723	89682.676
PHIEG		0.197	0.084	0.228	0.108	0.149	0.109	0.206	0.177
LAMUP		2.495E 05	2.058E 06	1.961E 05	3.512E 05	3.541E 05	1.120E 06	2.520E 05	2.830E 05

		TEST RUN NO.	10-2C1	10-3	10-4C1	10-5	10-6	10-7	10-8	10-9
		PLUG INSERT NO.	7	7	7	7	7	7	7	7
MEAN QUALITY INCREMENT			0.1000	0.0630	0.0865	0.0135	0.0135	0.0485	0.0880	0.1100
DX			0.200	0.126	0.173	0.027	0.027	0.097	0.176	0.220
DE	FT		0.008	0.006	0.008	0.006	0.006	0.006	0.008	0.008
DLX	FT		2.000	0.550	1.550	0.350	0.250	0.500	2.000	2.000
DPX	PSI		11.000	68.000	9.000	37.000	33.000	55.000	7.000	7.000
PMX	PSI		302.500	339.000	295.500	334.500	315.500	341.500	295.500	335.500
QX-FLUX	B/HR-FT2		5.430E 04	1.217E 05	6.714E 04	4.686E 04	6.400E 04	1.179E 05	5.380E 04	7.617E 04
UX	B/HR-FT2-F		1022.644	1567.551	1668.419	982.757	1714.933	1863.585	1371.061	1490.053
DTM	DEG-F		53.100	77.660	40.240	47.680	37.320	63.260	39.240	51.120
DTCRX	DEG-F		35.158	192.445	33.967	48.515	47.817	170.540	35.135	48.370
DTCR2	DEG-F		234.977	1286.179	227.012	324.242	319.579	1139.785	234.824	323.273
NUDX			0.452	0.489	0.540	0.179	0.242	0.466	0.494	0.552
CX2			1.900	1.022	1.839	0.964	0.999	0.956	1.708	1.757
BETAX			1.074	0.626	1.242	0.216	0.333	0.557	1.055	1.213
REX			4.635E 04	2.541E 05	5.151E 04	2.913E 05	2.870E 05	2.902E 05	5.241E 04	5.811E 04
NUX			721.447	811.893	1181.766	510.099	898.297	964.074	971.143	1034.660
KX			52.383	35.866	69.102	58.408	74.569	44.034	70.863	54.479
LAMX			2.962E 03	4.498E 03	2.478E 03	3.006E 02	3.096E 02	3.061E 03	2.596E 03	3.996E 03
PHIFG			0.541	0.093	0.725	1.314	1.633	0.108	0.408	0.226
FG			0.032	0.	0.032	0.	0.	0.	0.032	0.032
PHI			20.042	0.	22.668	0.	0.	0.	12.749	7.067
MEAN QUALITY INCREMENT			0.3000	0.1630	0.2865	0.1135	0.1135	0.1485	0.2880	0.3100
DX			0.200	0.074	0.227	0.173	0.173	0.103	0.224	0.180
DE	FT		0.033	0.008	0.033	0.008	0.008	0.008	0.033	0.033
DLX	FT		0.750	0.350	1.550	1.450	1.250	0.650	1.500	1.250
DPX	PSI		1.000	3.000	2.000	7.000	6.000	3.000	3.000	3.000
PMX	PSI		296.500	303.500	290.000	312.500	296.000	310.000	290.500	330.500
QX-FLUX	B/HR-FT2		1.448E 05	1.124E 05	8.791E 04	7.247E 04	8.202E 04	9.629E 04	9.130E 04	9.972E 04
UX	B/HR-FT2-F		1723.475	1011.802	1184.826	966.282	1283.952	998.904	1228.110	1121.406
DTM	DEG-F		84.020	111.040	74.200	75.000	63.880	96.400	74.340	88.920
DTCRX	DEG-F		20.902	54.055	22.345	44.206	43.296	55.719	22.829	26.992
DTCR2	DEG-F		139.695	361.272	149.340	295.443	289.364	379.077	152.575	180.396
NUDX			0.514	0.580	0.419	0.465	0.545	0.545	0.427	0.407
CX2			3.307	2.511	2.713	2.042	2.062	2.215	2.714	2.663
BETAX			2.128	1.823	1.421	1.187	1.405	1.511	1.451	1.355
REX			7.134E 04	4.532E 04	7.928E 04	5.158E 04	5.078E 04	5.165E 04	8.065E 04	8.933E 04
NUX			5246.470	713.453	3621.460	678.401	909.158	702.150	3752.583	3356.621
KX			33.097	25.051	37.465	37.102	43.531	28.863	37.395	31.314
LAMX			3.927E 04	7.525E 03	3.912E 04	4.051E 03	4.112E 03	6.875E 03	4.007E 04	4.744E 04
PHIFG			0.750	0.394	0.638	0.357	0.359	0.529	0.946	0.850
FG			0.	0.032	0.	0.032	0.032	0.032	0.	0.
PHI			0.	12.310	0.	11.159	11.206	16.525	0.	0.

TEST RUN NO.		10-2C1	10-3	10-4C1	10-5	10-6	10-7	10-8	10-9
PLUG INSERT NO.		7	7	7	7	7	7	7	7
MEAN QUALITY INCREMENT		0.5000	0.3000	0.5000	0.2550	0.2550	0.3000	0.5000	0.5000
DX		0.200	0.200	0.200	0.110	0.110	0.200	0.200	0.200
DE	FT	0.033	0.008	0.033	0.008	0.008	0.008	0.033	0.033
DLX	FT	0.700	0.900	1.700	0.550	0.750	0.600	1.250	1.400
DPX	PSI	1.000	8.000	3.000	3.000	4.000	8.000	2.000	2.000
PMX	PSI	295.500	298.000	287.500	307.500	291.000	302.000	288.000	328.000
QX-FLUX	B/HR-FT2	1.551E 05	1.181E 05	7.069E 04	1.215E 05	8.692E 04	2.026E 05	9.782E 04	9.892E 04
UX	B/HR-FT2-F	1388.488	891.619	654.492	1217.268	982.345	1628.565	896.271	798.934
DTM	DEG-F	111.740	132.440	108.000	99.800	88.480	124.380	109.140	123.620
DTCRX	DEG-F	50.109	91.133	55.594	91.160	89.341	104.108	56.562	63.139
DTCR2	DEG-F	187.833	609.077	208.395	609.259	597.096	695.794	212.023	236.676
NUDX		0.631	0.766	0.438	0.809	0.740	1.030	0.512	0.462
CX2		3.559	2.426	2.767	2.164	1.969	2.552	2.982	2.855
BETAX		2.809	2.324	1.515	2.189	1.822	3.289	1.909	1.648
REX		7.139E 04	4.548E 04	7.943E 04	5.172E 04	5.097E 04	5.188E 04	8.079E 04	8.946E 04
NUX		4229.371	630.562	2003.619	856.676	697.772	1149.187	2742.922	2394.250
KX		24.885	20.998	25.736	27.877	31.420	22.363	25.468	22.486
LAMX		1.383E 05	2.731E 04	1.531E 05	2.090E 04	2.129E 04	3.013E 04	1.551E 05	1.558E 05
PHIFG		0.288	0.119	0.284	0.079	0.078	0.138	0.249	0.193
FG		0.	0.032	0.	0.032	0.032	0.032	0.	0.
PHI		0.	3.716	0.	2.469	2.429	4.306	0.	0.
MEAN QUALITY INCREMENT		0.7000	0.5000	0.7000	0.4550	0.4550	0.5300	0.7000	0.7000
DX		0.200	0.200	0.200	0.290	0.290	0.260	0.200	0.200
DE	FT	0.033	0.008	0.033	0.033	0.033	0.008	0.033	0.033
DLX	FT	0.800	0.500	2.200	1.000	1.150	0.750	1.700	1.800
DPX	PSI	2.000	4.000	4.000	2.000	2.000	7.000	5.000	4.000
PMX	PSI	294.000	292.000	284.000	306.000	288.000	294.500	284.500	325.000
QX-FLUX	B/HR-FT2	1.358E 05	2.126E 05	5.462E 04	1.762E 05	1.494E 05	2.107E 05	7.193E 04	7.694E 04
UX	B/HR-FT2-F	974.418	1301.941	383.702	1332.457	1234.758	1277.058	502.415	479.383
DTM	DEG-F	139.320	161.260	140.520	132.200	120.640	164.960	143.160	160.500
DTCRX	DEG-F	54.370	218.884	60.374	53.117	52.084	257.055	61.425	68.587
DTCR2	DEG-F	203.307	820.485	226.313	199.110	195.238	963.570	230.252	257.100
NUDX		0.682	1.273	0.437	0.575	0.566	1.307	0.496	0.462
CX2		3.968	2.924	3.025	3.590	3.435	2.748	3.226	3.121
BETAX		3.386	4.654	1.651	2.584	2.431	4.493	2.001	1.805
REX		7.147E 04	4.567E 04	7.963E 04	7.940E 04	7.831E 04	5.215E 04	8.100E 04	8.961E 04
NUX		2970.889	924.206	1192.567	4037.529	3791.061	905.124	1540.964	1438.680
KX		19.957	17.029	19.777	21.043	23.040	16.856	19.412	17.345
LAMX		4.240E 05	9.743E 04	4.722E 05	1.146E 05	1.171E 05	1.273E 05	4.782E 05	4.795E 05
PHIFG		0.256	0.038	0.148	0.399	0.348	0.030	0.231	0.152
FG		0.	0.032	0.	0.	0.	0.032	0.	0.
PHI		0.	1.182	0.	0.	0.	0.945	0.	0.

		TEST RUN NO.	10-2C1	10-3	10-4C1	10-5	10-6	10-7	10-8	10-9
		PLUG INSERT NO.	7	7	7	7	7	7	7	7
MEAN QUALITY INCREMENT			0.9000	0.7000	0.9000	0.7000	0.7000	0.7300	0.9000	0.9000
DX			0.200	0.200	0.200	0.200	0.200	0.140	0.200	0.200
DE	FT		0.033	0.008	0.033	0.033	0.033	0.033	0.033	0.033
DLX	FT		4.000	0.300	5.800	0.950	1.000	0.550	4.800	4.300
DPX	PSI		5.000	3.000	10.000	1.000	2.000	2.000	7.000	8.000
PMX	PSI		290.500	288.500	277.000	303.500	286.000	290.000	273.500	319.000
QX-FLUX	B/HR-FT2		2.715E 04	3.543E 05	2.072E 04	1.279E 05	1.185E 05	1.547E 05	2.547E 04	3.221E 04
UX	B/HR-FT2-F		161.288	1842.403	117.676	749.837	745.062	778.475	142.327	161.556
DTM	DEG-F		156.340	192.280	176.060	170.540	159.080	198.700	178.980	199.360
DTCRX	DEG-F		40.413	237.689	44.951	60.653	59.498	60.286	45.713	51.093
DTCR2	DEG-F		151.489	890.976	168.501	227.359	223.030	225.984	171.355	191.523
NUDX			0.380	1.960	0.330	0.592	0.603	0.637	0.362	0.368
CX2			3.774	3.778	3.412	3.872	3.809	4.348	3.574	3.597
BETAX			1.792	9.257	1.409	2.867	2.872	3.464	1.619	1.657
PEX			7.165E 04	4.579E 04	8.004E 04	7.947E 04	7.842E 04	8.021E 04	8.136E 04	8.991E 04
NUX			492.827	1310.740	362.638	2273.759	2283.033	2379.434	438.198	486.245
KX			16.514	14.456	15.779	16.311	17.471	13.990	15.522	13.961
LAMX			2.018E 06	3.004E 05	2.271E 06	4.534E 05	4.644E 05	5.618E 05	2.293E 06	2.297E 06
PHIEG			0.077	0.024	0.093	0.089	0.168	0.270	0.068	0.076
EG			0.	0.032	0.	0.	0.	0.	0.	0.
PHI			0.	0.746	0.	0.	0.	0.	0.	0.

MEAN QUALITY INCREMENT			0.	0.9000	0.	0.9000	0.9000	0.9000	0.	0.
DX			0.	0.200	0.	0.200	0.200	0.200	0.	0.
DE	FT		0.	0.033	0.	0.033	0.033	0.033	0.	0.
DLX	FT		0.	3.700	0.	4.300	3.700	2.100	0.	0.
DPX	PSI		0.	5.000	0.	4.000	5.000	3.000	0.	0.
PMX	PSI		0.	284.500	0.	301.000	282.500	287.500	0.	0.
QX-FLUX	B/HR-FT2		0.	2.872E 04	0.	2.825E 04	3.203E 04	5.787E 04	0.	0.
UX	B/HR-FT2-F		0.	129.584	0.	139.557	167.190	255.517	0.	0.
DTM	DEG-F		0.	221.660	0.	202.440	191.600	226.500	0.	0.
DTCRX	DEG-F		0.	39.634	0.	45.054	44.230	45.278	0.	0.
DTCR2	DEG-F		0.	148.567	0.	168.884	165.797	169.724	0.	0.
NUDX			0.	0.343	0.	0.349	0.391	0.480	0.	0.
CX2			0.	4.156	0.	3.756	3.903	4.649	0.	0.
BETAX			0.	1.783	0.	1.638	1.907	2.789	0.	0.
PEX			0.	7.041E 04	0.	7.959E 04	7.863E 04	8.036E 04	0.	0.
NUX			0.	397.450	0.	423.697	513.437	782.222	0.	0.
KX			0.	12.538	0.	13.739	14.503	12.272	0.	0.
LAMX			0.	2.016E 06	0.	2.149E 06	2.212E 06	2.226E 06	0.	0.
PHIEG			0.	0.085	0.	0.047	0.068	0.069	0.	0.
EG			0.	0.	0.	0.	0.	0.	0.	0.
PHI			0.	0.	0.	0.	0.	0.	0.	0.

APPENDIX B

CL-4 BOILER TEST DATA REDUCTION PROGRAM

APPENDIX B

CL-4 BOILER TEST DATA REDUCTION PROGRAM

The test data representation as provided on the NaK temperature profile recording sheets (Figure B-1) was utilized to reduce these data and establish the boiler thermal and dynamic operating parameters in dimensional and non-dimensional form for each data point set. The test data reduction program as utilized with the IBM-7094 Mod. 2 computer consists of two steps. The first computer input step provides the heat balance and the boiler overall thermal and dynamic operating parameters. These results in conjunction with NaK temperature profile representations are then used to generate the second computer input set (Figure B-2), which comes into the program just prior to equation 75. This results in the determination of the thermal and dynamic operating parameters in dimensional and non-dimensional form for the boiler preheat and vapor quality sections. The vapor quality section analysis was performed on a local boiling heat transfer basis by dividing the section into 20% quality increments. The mean boiling heat transfer parameters in the plug insert section and the unplugged tube section were determined as well.

FIRST INPUT SET

D, in. - Boiler tube ID

wi, in. - Machined plug insert thread width

hi, in. - Machined plug insert thread height

δ_0, in. - Wire diameter

p_1, in. - Plug insert wire or thread pitch in preheat section

p_2, in. - Plug insert wire pitch in vapor quality section

p_3, in. - Unplugged tube wire pitch

ΔL_{p_1}, in. - Preheat section plug insert length

ΔL_{p_2}, in. - Vapor quality section plug insert length

g_c, $\frac{\text{lbm-ft}}{\text{lbf-sec}^2}$ - Gravitational constant

---

w_N, lbm/hr - NaK flow rate

T_{Nbi}, °F - NaK inlet temperature

T_{Nbo}, °F - NaK exit temperature

ΔT_N, °F - NaK temperature drop

w, lbm/hr - Mercury flow rate

T_{Hbi}, °F - Mercury inlet temperature

T_{Hbo}, °F - Mercury vapor exit temperature

P_{Hbi}, psia - Mercury inlet pressure

P_1, psia - Mercury pressure at preheat section end point

P_2, psia - Mercury pressure at plug insert end point

P_{Hbo}, psia - Mercury pressure at boiler exit

ΔP_{PH}, psi - Preheat section pressure drop

ΔP_x, psi - Plug insert vapor section pressure drop

T_{N-2}, °F - NaK temperature at plug insert end point

f_{g-PL}, - Frictional pressure drop coefficient for all vapor flow in the plug insert vapor quality section

HEAT BALANCE

1.	$q_N = .21\ w_N\ \Delta T_N$	Btu/hr		
2.	$T_S = f(P_{Hbo})$	°F	Fig. B-4	Re: 1
3.	$\Delta T_{PH} = T_2 - T_{Hbi}$	°F		
4.	$\Delta T_{SH} = T_{Hbo} - T_2$	°F		
5.	$q_{PH} = .0325\ w\ \Delta T_3$	Btu/hr		
6.	$h_{fv} = f\ (T_2)$	Btu/lbm	Fig. B-13	Re: 1
7.	$q_B = w\ h_6$	Btu/hr		
8.	$q_{SH} = .025\ w\ \Delta T_4$	Btu/hr		
9.	$q_{Hg} = q_5 + q_7 + q_8$	Btu/hr		
10.	$q_{HL} = \frac{q_1 - q_9}{3413}$	kw		
11.	$w_{N-HL} = \frac{3413\ q_{10}}{.21\ \Delta T_N}$	lbm/hr		
12.	$w_{N-Net} = w_N - w_{11}$	lbm/hr		

PREHEAT SECTION

13.	$\tan \alpha_1 = \frac{\pi D}{p_1}$		
14.	$\sin \alpha_1 = f(\tan \alpha)_{13}$		
15.	$\cos \alpha_1 = f(\tan \alpha)_{13}$		
16.	$\ell_1 = p_1 \sin \alpha_{14} - wi$	in.	
17.	$A_{C-PH} = \frac{\ell_{16}\ hi}{144}$	ft^2	

18. $P_{W-PH} = \frac{2(\ell_{16} - hi)}{12}$ ft

19. $De_{PH} = \frac{4\ A_{17}}{P_{18}}$ ft

20. $\Delta L'_{PH} = \frac{\Delta L_{P1}}{12 \cos \alpha_{15}}$ ft

21. $G_{PH-1} = \frac{w}{A_{17}}$ lbm/hr-ft^2

22. $G_{PH-2} = \frac{G_{21}}{3600}$ lbm/sec-ft^2

23. $T_{S-1} = f(P_1)$ °F Fig. B-4 Re: 1

24. $\rho_{L-1} = f(T_{23})$ lbm/ft^3 Fig. B-1 Re: 1

25. $u_{L-1} = \frac{G_{22}}{\rho_{24}}$ ft/sec

26. $T_{L-M} = \frac{T_{Hbi} + T_{23}}{2}$ °F

27. $\mu_{L-M} = f(T_{26})$ lbm/hr-ft Fig. B-6 Re: 1

28. $Re_{L-M} = \frac{G_{21}\ De_{19}}{\mu_{27}}$

29. $\rho_{L-M} = f(T_{26})$ lbm/hr-ft Fig. B-1 Re: 1

30. $f_L = \frac{144 \times 2g_c\ De_{19}}{\Delta L'_{20}} \quad \frac{\rho_{29}}{G_{22}^2} \frac{\Delta P_{PH}}{}$

31. $c_{p-LM} = f(T_{26})$ Btu/lbm-°F Fig. B-5 Re: 1

32. $q_{PH} = w\ c_{p_{31}} (T_{23} - T_{Hbi})$ Btu/hr

33. $\Delta T_{N-PH} = \frac{q_{32}}{.21\ w_{12}}$ °F

34. $T_{NOO} = T_{Nbo} + \Delta T_{33}$ °F

35. $k_{L-M} = f(T_{26})$ Btu/hr-ft-°F

36. $Pr = \frac{c_{p_{31}}\ \mu_{27}}{k_{35}}$

PLUG INSERT VAPOR QUALITY SECTION

37. $\tan \alpha_2 = \frac{\pi D}{p_2}$

38. $\sin \alpha_2 = f(\tan \alpha)_{37}$

39. $\cos \alpha_2 = f(\tan \alpha)_{37}$

40. $\ell_2 = p_2 \sin \alpha_{38} - \delta$ in.

41. $A_{C-x} = \frac{\ell_{40}\ \delta}{144}$ ft^2

42. $P_{W-x} = \frac{2(\ell_{40} + \delta)}{12}$ ft

43. $De_x = \frac{4\ A_{41}}{P_{42}}$ ft

44. $\Delta L'_x = \frac{\Delta L\ p_2}{12 \cos \alpha_{39}}$ ft

45. $G_{x-1} = \frac{w}{A_{41}}$ $lbm/hr\text{-}ft^2$

46. $G_{x-2} = \frac{G_{45}}{3600}$ $lbm/sec\text{-}ft^2$

47. $\Delta T_{N-x} = T_{N-2} - T_{34}$ °F

48. $q_{N-x} = .21\ w_{12}\ \Delta T_{47}$ Btu/hr

49. $T_{S-2} = f(P_2)$ °F Fig. B-4 Re: 1

50. $T_{x-SM} = \frac{T_{23} + T_{49}}{2}$ °F

51. $h_{x-fv-M} = f(T_{50})$ Btu/lbm Fig. B-13 Re: 1

52. $x_{PL} = \frac{q_{48}}{w\ h_{51}}$

53. $\rho_{v-2} = 18.7 \frac{P_2}{T_{49} + 460}$ lbm/ft^3

54. $u_{v-PL-2} = \frac{x_{52}\ G_{46}}{\rho_{53}}$ ft/sec

UNPLUGGED TUBE VAPOR QUALITY SECTION

55. $A_{C-xx} = \frac{\pi}{4 \times 144} D^2$ ft^2

56. $\tan \alpha_3 = \frac{\pi D}{P_3}$

57. $G_{xx-1} = \frac{w}{A_{55}}$ lbm/hr-ft^2

58. $G_{xx-2} = \frac{G_{57}}{3600}$ lbm/sec-ft^2

59. $u_{v-T-2} = \frac{x_{52}\ G_{58}}{\rho_{53}}$ ft/sec

60. $h_{fv-2} = f(T_{49})$ Btu/lbm

61. $q_{N-xx} = (1-x_{52})\ w\ h_{60}$ Btu/hr

62. $\Delta T_{N-xx} = \frac{q_{61}}{.21\ w_{12}}$ °F

63. $\Delta T_{N-B} = \Delta T_{47} + \Delta T_{62}$ °F

64. $T_{N100} = T_{34} + \Delta T_{63}$ °F

65. $\Delta T_{N\Delta x} = \frac{\Delta T_{63}}{5}$ °F

66. $q_B = q_{48} + q_{61}$ Btu/hr

67. $q_{B\Delta x} = \frac{q_{66}}{5}$ Btu/hr

68. $T_{N00} = T_{Nbo} + \Delta T_{33}$ °F

69. $T_{N20} = T_{68} + \Delta T_{65}$ °F

70. $T_{N40} = T_{68} + 2\Delta T_{65}$ °F

71. $T_{N60} = T_{68} + 3\Delta T_{65}$ °F

72. $T_{N80} = T_{68} + 4\Delta T_{65}$ °F

73. $T_{N100} = T_{68} + 5\Delta T_{65}$ °F

74. $C = \frac{\pi D}{12}$ ft

PREHEAT SECTION

75. $\Delta L_{PHc} = L_{00} - .5$ ft

76. $A_{PH} = C_{74}\ \Delta L_{75}$ ft^2

77. $T_{S00} = f(P_{00})$ °F Fig. B-4 Re: 1

78. $q_{PHc} = .0325\ w\ (T_{77} - T_{Hbi})$ Btu/hr

79. $q''_{PH} = \frac{q_{78}}{A_{76}}$ Btu/hr-ft^2

80. $\Delta T_{PHi} = T_{Nbo} - T_{Hbi}$ °F

81. $\Delta T_{PHo} = T_{NOO} - T_{77}$ °F

82. $\Delta T_{PH-M} = \frac{\Delta T_{80} - \Delta T_{81}}{\ell n \frac{\Delta T_{80}}{\Delta T_{81}}}$ °F

83. $h_{PH} = \frac{q''_{79}}{\Delta T_{82}}$ Btu/hr-ft^2-°F

84. $Nu_{PH} = \frac{De\ h_{83}}{k_{35}}$

85. $T_{PH-M} = \frac{T_{Hbi} + T_{77}}{2}$ °F

86. $\rho_{PH-M} = f(T_{85})$ lbm/ft^3 Fig. B-1 Re: 1

87. $\mu_{PH-M} = f(T_{85})$ lbm/hr-ft Fig. B-6 Re: 1

88. $Re_{PH} = \frac{G_1\ De}{\mu_{87}}$

89. $\Delta P_{PHc} = P_{Hbi} - P_{00}$

90. $f_{PH} = f_{30} \frac{\rho_{86}}{\rho_{29}} \frac{\Delta P_{89}}{\Delta P_{PH}} \frac{\Delta L_{20}}{\Delta L_{75}} \cos \alpha$

91. $Pe_{PH} = Re_{88}\ Pr_{36}$

92. $\Delta T_{00} = T_{NOO} - T_{77}$ °F

MEAN QUALITY INCREMENT

93. $\bar{x} = \frac{x_n + x_{n+1}}{2}$

94. $\Delta x = x_{n+1} - x_n$

95. $\Delta L = L_{x_{n+1}} - L_{x_n}$ ft

96. $\Delta P = P_n - P_{n+1}$ psi

97. $P_M = \frac{P_n + P_{n+1}}{2}$ psia

98. $T_{N-M} = \frac{T_{Nx_n} + T_{Nx_{n+1}}}{2}$ °F

99. $A_{\bar{x}} = C_{74}\ \Delta L_{95}$ ft^2

100. $q''_{\bar{x}} = \frac{Z_{\bar{x}}\ q_{67}}{A_{99}}$ $Btu/hr\text{-}ft^2$

101. $T_{S-M} = f(P_{97})$ °F Fig. B-4 Re: 1

102. $\Delta T_M = T_{98} - T_{101}$ °F

103. $h = \frac{q''_{100}}{\Delta T_{102}}$ $Btu/hr\text{-}ft^2\text{-}°F$

104. $\rho_L = f(T_{101})$ lbm/ft^3 Fig. B-1 Re: 1

105. $\rho_v = f(T_{101})$ lbm/ft^3 Fig. B-8 Re: 1

106. $\mu_L = f(T_{101})$ lbm/hr-ft Fig. B-6 Re: 1

107. $\mu_v = f(T_{101})$ lbm/hr-ft Fig. B-11 Re: 1

108. $k_L = f(T_{101})$ Btu/hr-ft-°F Fig. B-7 Re: 1

109. $k_v = f(T_{101})$ Btu/hr-ft-°F Fig. B-12 Re: 1

110. $\Delta L' = \frac{\Delta L_{95}}{\cos \alpha}$ ft

111. $\phi f_g = 144 \frac{2 g_c \, De \, \Delta P_{96} \, \rho_{105}}{\Delta L'_{110} \, (\bar{x}_{93} \, G_2)^2}$

112. $Re = \frac{G_1 \, De}{\mu_{107}}$

113. $\phi = \frac{(\phi \, f_g)_{111}}{f_g}$

114. $\lambda = Re_{112}^{.8} \; \frac{\mu_{107}}{\mu_{106}} \; \frac{\rho_{104}}{\rho_{105}} \; \frac{\bar{x}_{93}^{1.8}}{1-\bar{x}_{93}}$

115. $Nu = \frac{De \, h_{103}}{k_{109}}$

116. $h_{fv} = f(T_{101})$ Btu/lbm Fig. B-17 Re: 1

117. $K = \frac{h_{116} \, \mu_{107}}{k_{109} \, \Delta T_{102}}$

118. $\Delta T_{cr-1} = \frac{h_{116} \, \mu_{107} \, C_{\bar{x}}^2 \, (7488)^{\frac{1}{2}} \, (k_{109}/k_{108})^3 \, Re_{112} \, E_{\bar{x}} \, (1-\bar{x}_{93})^{\frac{1}{2}} \, \bar{x}_{93}}{k_{109} \left(\frac{12 \, De}{\delta}\right)^{3/2} \left(\frac{\rho_{105}}{\rho_{104}}\right)^{1/2}}$

Note: If $\Delta T_{118} > \Delta T_{102}$ use Eq. 119

If $\Delta T_{118} < \Delta T_{102}$ use Eq. 120

119. $$Nu_{\delta} = \left[\frac{32\ Nu_{115}}{(k_{108}/k_{109})^2 \left(\frac{12\ De}{\delta}\right)^2 (\rho_{105}/\rho_{104}) \frac{(1-\bar{x}_{93})^{1/3}}{\bar{x}_{93}}} \right]^{1/2}$$

120. $$\Delta T_{cr-2} = C_{\bar{x}}^3\ K_{117}\ \Delta T_{102} \frac{(936)^{3/4} (k_{109}/k_{108})^3\ Re_{112}\ E_{\bar{x}}\ (1-\bar{x}_{93})^{1/2}\ \bar{x}_{93}}{6^{1/4} \left(\frac{12\ De}{\delta}\right)^{3/2} (\rho_{105}/\rho_{104})^{1/2}\ \beta_{\bar{x}}}$$

Note: If $\Delta T_{120} > \Delta T_{102}$ use Eq. 121.

If $\Delta T_{120} < \Delta T_{102}$ use Eq. 122.

121. $$C_x = \left[\frac{Nu_{115}}{234 \left(\frac{k_{109}}{k_{108}}\right)^4 \left(\frac{\delta}{12\ De}\right) E_{\bar{x}}^2\ Re_{112}^2\ K_{117}^2\ (1-\bar{x}_{93})^{4/3}\ \bar{x}_{93}} \right]^{1/4}$$

122. $$\beta_x = \frac{4\ Nu_{115}}{6^{1/3} \left(\frac{12\ De}{\delta}\right) \left(Re_{112}\ E_{\bar{x}}\ \frac{\rho_{105}}{\rho_{104}}\ K_{117}\right)^{2/3} \frac{(1-\bar{x}_{93})^{2/3}}{\bar{x}_{93}}}$$

PLUG INSERT VAPOR QUALITY SECTION

123. $\Delta L_{PL-x} = L_{PL} - L_{00}$ ft.

124. $A_x = C_{74}\ \Delta L_{123}$ ft^2

125. $q'' = \frac{q_{48}}{A_{124}}$ $Btu/hr\text{-}ft^2$

126. $T_{S-MPL} = f(P_M)$ °F Fig. B-4 Re: 1

127. $\rho_{v-MPL} = 18.7 \frac{P_M}{T_{126} + 460}$ lbm/ft^3

128. $\mu_{v-MPL} = f(T_{126})$ lbm/hr-ft Fig. B-11 Re: 1

129. $\Delta L'_{PL-x} = \frac{\Delta L_{123}}{\cos \alpha_{39}}$ ft

130. $\bar{x}_{PL} = \frac{1}{2} x_{52}$

131. $(\phi f_g)_{PL} = 144 \frac{2g_c De_{43} \Delta P_{PL-x} \rho_{127}}{\Delta L_{129} (\bar{x}_{130} G_{46})^2}$

132. $Re_{PL-x} = \frac{G_{45} De_{43}}{\mu_{128}}$

133. $\rho_{L-MPL-x} = f(T_{126})$ lbm/ft^3 Fig. B-1 Re: 1

134. $\mu_{L-MPL-x} = f(T_{126})$ lbm/hr-ft

135. $\lambda_{MPL} = Re_{132}^{.8} \frac{\mu_{128}}{\mu_{134}} \frac{\rho_{133}}{\rho_{127}} \frac{\bar{x}_{130}^{1.8}}{1-\bar{x}_{130}}$

136. $\Delta T_{MPL-x} = T_{NMx} - T_{126}$ °F

137. $h_{MPL-x} = \frac{q''_{125}}{\Delta T_{136}}$ Btu/hr-ft^2-°F

UNPLUGGED TUBE VAPOR QUALITY SECTION

138. $\Delta L_{UPL-x} = L_{100} - L_{xPL}$ ft

139. $A_{UPL-x} = C_{74} \Delta L_{138}$ ft^2

140. $q''_{UPL-x} = \frac{q_{61}}{A_{139}}$ Btu/hr-ft^2

141. $T_{S-MUPL} = f(P_{M-UPL})$ °F

142. $\rho_{v-MUPL} = 18.7 \frac{P_{M-UPL}}{T_{141} + 460}$ lbm/ft^3

143. $\rho_{L-MUPL} = f(T_{141})$ lbm/ft^3 Fig. B-1 Re: 1

144. $\mu_{v\text{-}MUPL} = f(T_{141})$ lbm/hr-ft Fig. B-11 Re: 1

145. $\mu_{L\text{-}MUPL} = f(T_{141})$ lbm/hr-ft Fig. B-6 Re: 1

146. $$(\phi f_g)_{UPL} = 144 \frac{2 g_c D \Delta P_{UPL} \rho_{142}}{12 \Delta L_{UPL} (\bar{x}_{UPL} G_{58})^2}$$

147. $$Re = \frac{G_{57} D}{12 \mu_{144}}$$

148. $$\lambda = Re_{147}^{.8} \frac{\mu_{144}}{\mu_{145}} \frac{\rho_{143}}{\rho_{142}} \frac{\bar{x}_{UPLM}^{1.8}}{1-\bar{x}_{UPLM}}$$

149. $\Delta T_{M\text{-}UPL} = T_{NMx} - T_{141}$ °F

150. $$h_{MUPL} = \frac{q''_{140}}{\Delta T_{149}}$$ Btu/hr-ft^2-°F

Reference

1. Properties of SNAP-8 Fluids, NaK and Mercury, ET-378, March 1964, Aerojet-General Corporation.

NOMENCLATURE

A - Area

C - Circumference, also a constant

c_p - Specific heat at constant pressure

D_e - Equivalent tube diameter

E - Geometric constant

f - Friction factor

$f( )$ - Function of ( )

G - Specific mass flow

h - Heat transfer coefficient

h_{fv} - Latent heat

K - $\left(\frac{\mu_v \, h_{fv}}{k_v \, \Delta T_m} \right)$

k - Thermal conductivity

ℓ_1 - Helical flow passage width in preheat section

ℓ_2 - Helical flow passage width in plug insert vapor section

ΔL - Axial tube length

$\Delta L'$ - Flow passage helical length

Nu - Nusselt number

Nu_δ - Droplet Nusselt number

P - Pressure

ΔP - Pressure drop

P_W - Wetted perimeter

Pe - Peclet number

Pr - Prandtl number

NOMENCLATURE (Cont.)

q	-	Heat transfer rate
q''	-	Heat flux
Re	-	Reynolds number
u	-	Velocity
w	-	Mass flow rate
x	-	Vapor quality
Δx	-	Vapor quality increment
$\bar{x}$	-	Mean vapor quality
$Z_{\bar{x}}$	-	$\frac{\Delta x}{.20}$

GREEK SYMBOLS

α - Swirl wire angle

β - $\frac{Nu \text{ (actual)}}{Nu_{\delta} \text{ (film-sphere)}}$

λ - Martinelli correlating parameter

δ - Droplet diameter, Swirl wire diameter

ρ - Density

μ - Viscosity

ϕ - Two-phase flow ration $\Delta P_{TP}/\Delta P_{v}$

SUBSCRIPTS

B	-	Boiling
C	-	Flow cross-section
Hg	-	Mercury
HL	-	Heat loss
L	-	Liquid
M	-	Mean
N	-	NaK
PH	-	Preheat section
PL	-	Plugged section
S	-	Saturation
SH	-	Superheat section
SM	-	Saturation-Mean
T	-	Tube
UPL	-	Unplugged section
c	-	Corrected
cr	-	Critical
f	-	Liquid at saturation temperature
g	-	Gas, vapor
i	-	Inlet
o	-	Outlet, exit
v	-	Vapor
x	-	Plug insert vapor quality section
xx	-	Vapor quality section in unplugged tube

SUBSCRIPTS (cont.)

Unless otherwise indicated, numerical subscripts refer to numbered equations.

Exceptions:

-1 - Refers to the point at which P_1 is measured

-2 - Refers to the point at which P_2 is measured

00 - Liquid-vapor interface location

20 - 20% quality location

40 - 40% quality location

60 - 60% quality location

80 - 80% quality location

100 - 100% quality location

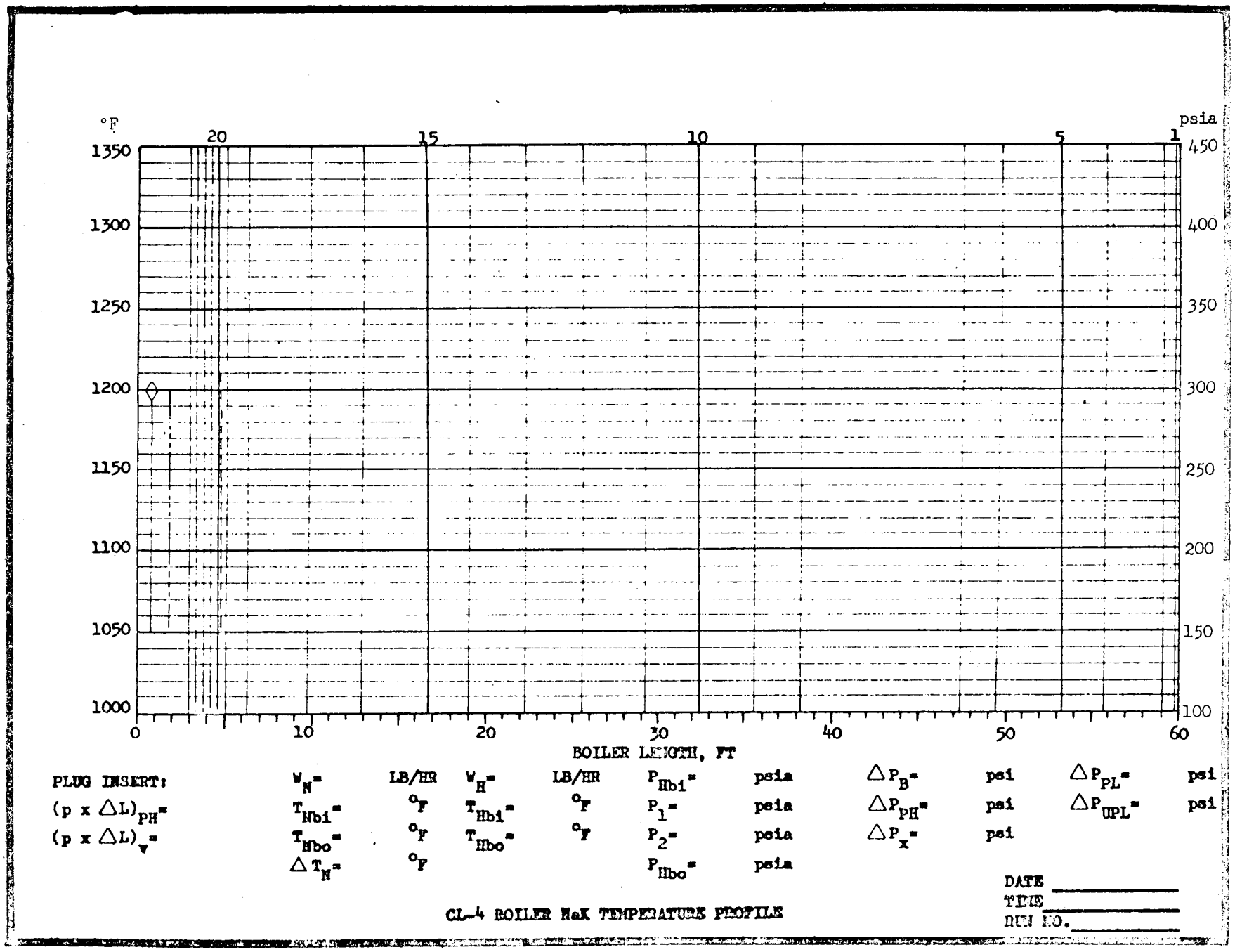

°F
psia
20
15
10
5
1
1350
1300
1250
1200
1150
1100
1050
1000
450
400
350
300
250
200
150
100
0
10
20
30
40
50
60
BOILER LENGTH, FT
PLUG INSERT:
$(p \times \Delta L)_{PH}$=
$(p \times \Delta L)_{V}$=
W_N= LB/HR
T_{Nbi}= °F
T_{Nbo}= °F
ΔT_N= °F
W_H= LB/HR
T_{Hbi}= °F
T_{Hbo}= °F
P_{Hbi}= psia
P_1= psia
P_2= psia
P_{Hbo}= psia
ΔP_B= psi
ΔP_{PH}= psi
ΔP_x= psi
ΔP_{PL}= psi
ΔP_{UPL}= psi
DATE
TIME
RUN NO.
CL-4 BOILER NaK TEMPERATURE PROFILE

Fig. B-1

BOILER TEST DATA REDUCTION - Second Input Set

	PREHEAT SECT.	VAPOR QUALITY SECTIONS						PLUG INS. QUAL. SECT.	UPL. TUBE QUAL. SECT.
	0	00	x_1	x_2	x_3	x_4	x_5	x_6	x_{PL-EX}	
T_N									T_{N2}	
x		00							x_{PL}	
L	.5									
P	PHBI								P_2	
Δx			x_1	$x_2 - x_1$	$x_3 - x_2$	$x_4 - x_3$	$x_5 - x_4$	$x_6 - x_5$	x_{PL}	$x_{100} - x_{PL}$
$\bar{x}$	PREHEAT SECT.		$\frac{x_1}{2}$	$\frac{x_1 + x_2}{2}$	$\frac{x_2 + x_3}{2}$	$\frac{x_3 + x_4}{2}$	$\frac{x_4 + x_5}{2}$	$\frac{x_5 + x_6}{2}$	$x_{PL}/2$	$\frac{x_{100} + x_{PL}}{2}$
D_e	DEFI									
G_1	GPHI									
G_2										
cos α	COSAI									
E_x										
C_x										
θ_x										
Z_x										
ΔL	$L_{00} - .5$	$L_{x1} - L_{00}$	$L_{x2} - L_{x1}$	$L_{x3} - L_{x2}$	$L_{x4} - L_{x3}$	$L_{x5} - L_{x4}$	$L_{x6} - L_{x5}$		$L_{xPL} - L_{00}$	$L_{100} - L_{xPL}$
ΔP	$P_{Hbi} - P_{00}$	$P_{00} - P_{x1}$	$P_{x1} - P_{x2}$	$P_{x2} - P_{x3}$	$P_{x3} - P_{x4}$	$P_{x4} - P_{x5}$	$P_{x5} - P_{x6}$		$P_{00} - P_2$	$P_2 - P_{100}$
P_M		$\frac{P_{00} + P_{x1}}{2}$	$\frac{P_{x1} + P_{x2}}{2}$	$\frac{P_{x2} + P_{x3}}{2}$	$\frac{P_{x3} + P_{x4}}{2}$	$\frac{P_{x4} + P_{x5}}{2}$	$\frac{P_{x5} + P_{x6}}{2}$		$\frac{P_{00} + P_2}{2}$	$\frac{P_2 + P_{100}}{2}$
T_{NMx}		$\frac{T_{N00} + T_{Nx1}}{2}$	$\frac{T_{Nx1} + T_{Nx2}}{2}$	$\frac{T_{Nx2} + T_{Nx3}}{2}$	$\frac{T_{Nx3} + T_{Nx4}}{2}$	$\frac{T_{Nx4} + T_{Nx5}}{2}$	$\frac{T_{Nx5} + T_{Nx6}}{2}$		$\frac{T_{N00} + T_{N2}}{2}$	$\frac{T_{N2} + T_{100}}{2}$

2nd Input Set #

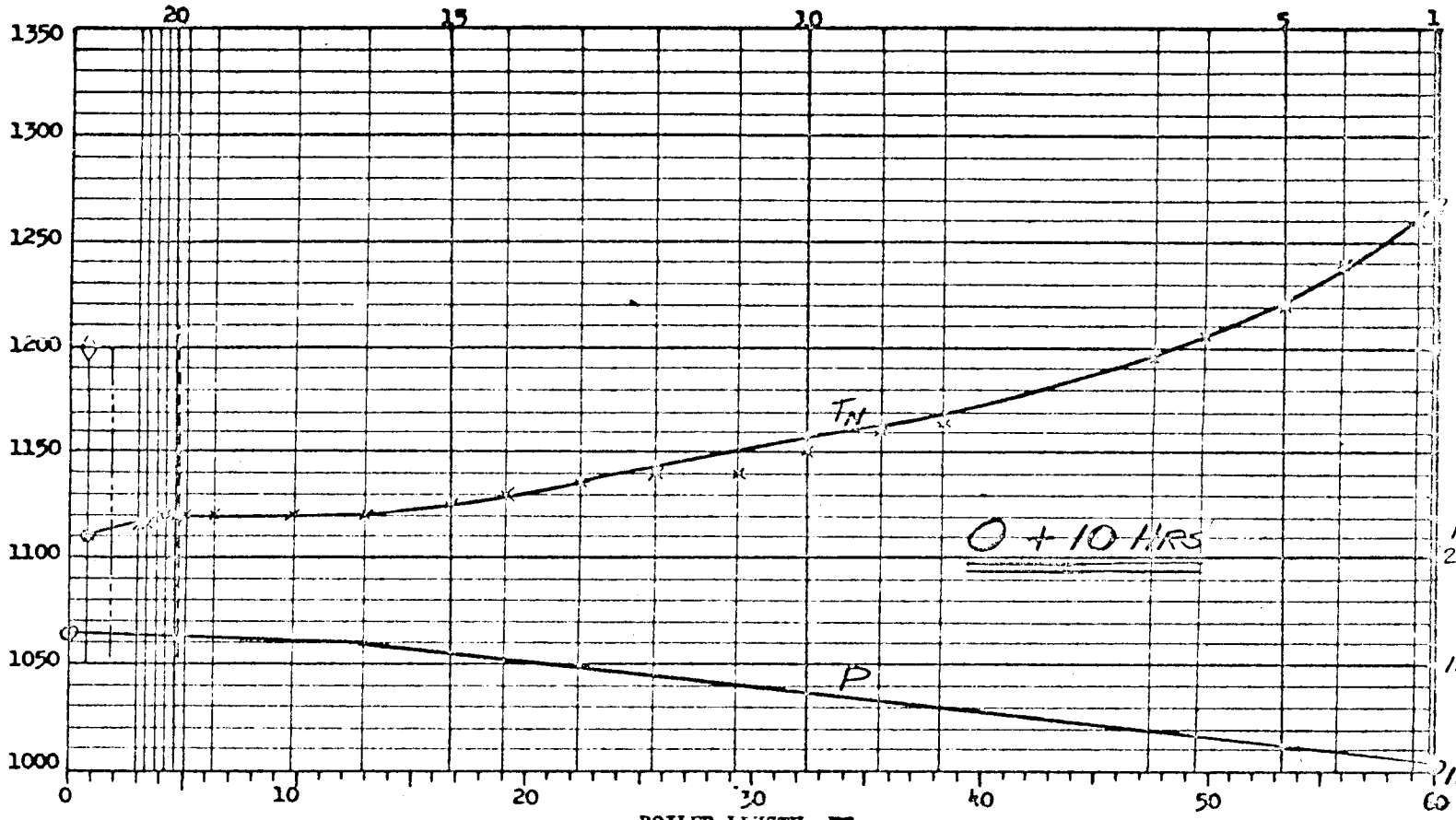
To be used with 1st Input #

Final Output Notation

Fig. B-2

APPENDIX C

NaK TEMPERATURE PROFILES AND ASSOCIATED TEST DATA



PLUG INSERT: #1

$(p \times \Delta L)_{PH}$ = 3/4" x 21"

$(p \times \Delta L)_{V}$ = 3/4" x 36"

W_N = 2250 LB/HR

T_{Nbi} = 1270 °F

T_{Nbo} = 1110 °F

ΔT_N = 160 °F

W_H = 517 LB/HR

T_{Hbi} = 510 °F

T_{Hbo} = 995 °F

P_{Hbi} = 165 psia

P_1 = — psia

P_2 = — psia

P_{Hbo} = 102 psia

ΔP_B = 63 psi

ΔP_{PH} = — psi

ΔP_x = — psi

ΔP_{PL} = — psi

ΔP_{UPL} = —. psi

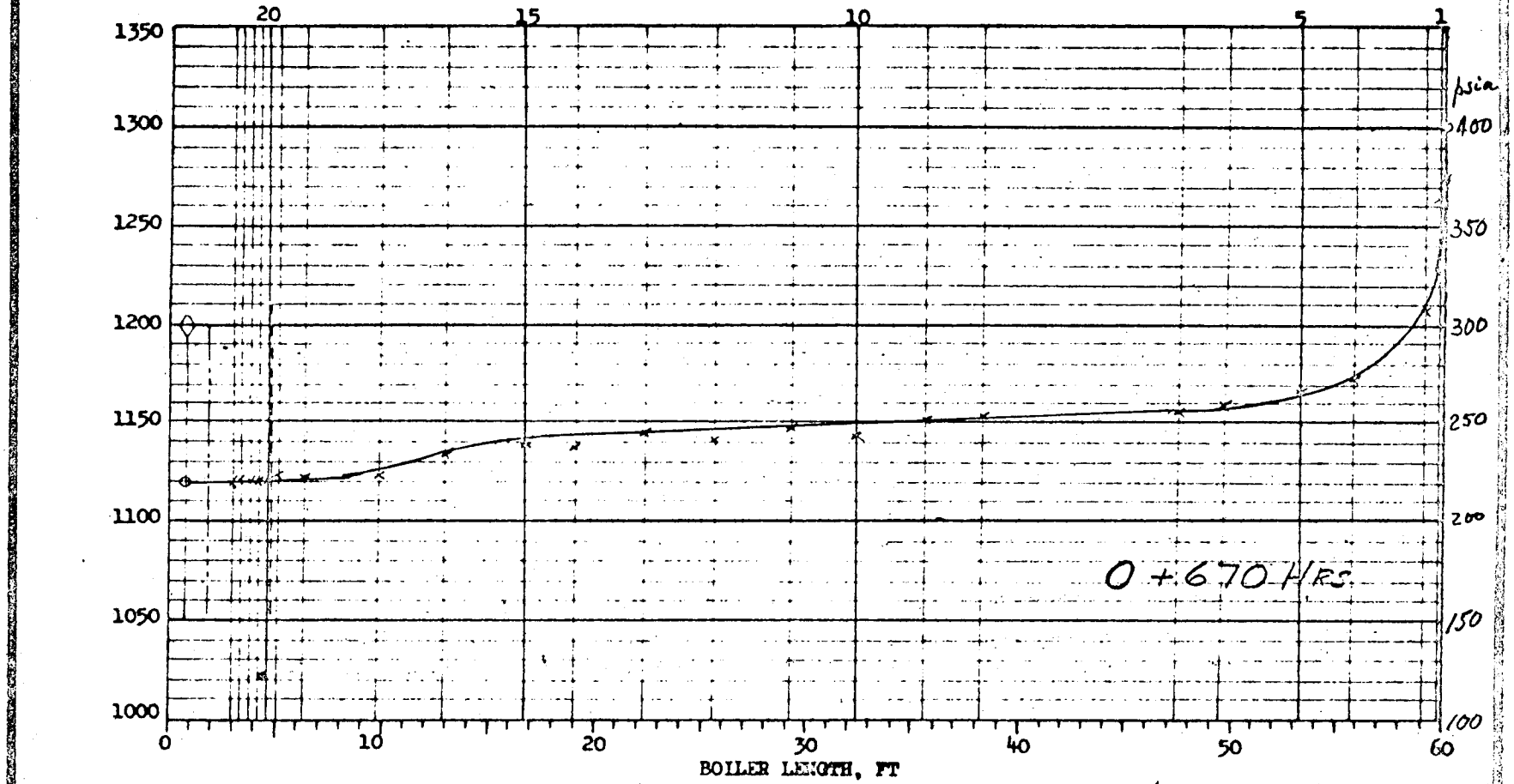
DATE 1/28/65

TIME 2210

RUN NO. 1-1

CL-4 BOILER NaK TEMPERATURE PROFILE

Fig. C-1



PLUG INSERT:

$W(p \times \Delta L)_{PH}$ = 3/4" x 21'

$W(p \times \Delta L)_{V}$ = 3/4" x 36'

W_N = 2100 LB/HR T_{Nbi} = 1300 °F T_{Nbo} = 1120 °F ΔT_N = 180 °F

W_H = 450 LB/HR T_{Hbi} = 495 °F T_{Hbo} = 1180 °F

P_{Hbi} = 300 psia P_1 = — psia P_2 = — psia P_{Hbo} = 260 psia

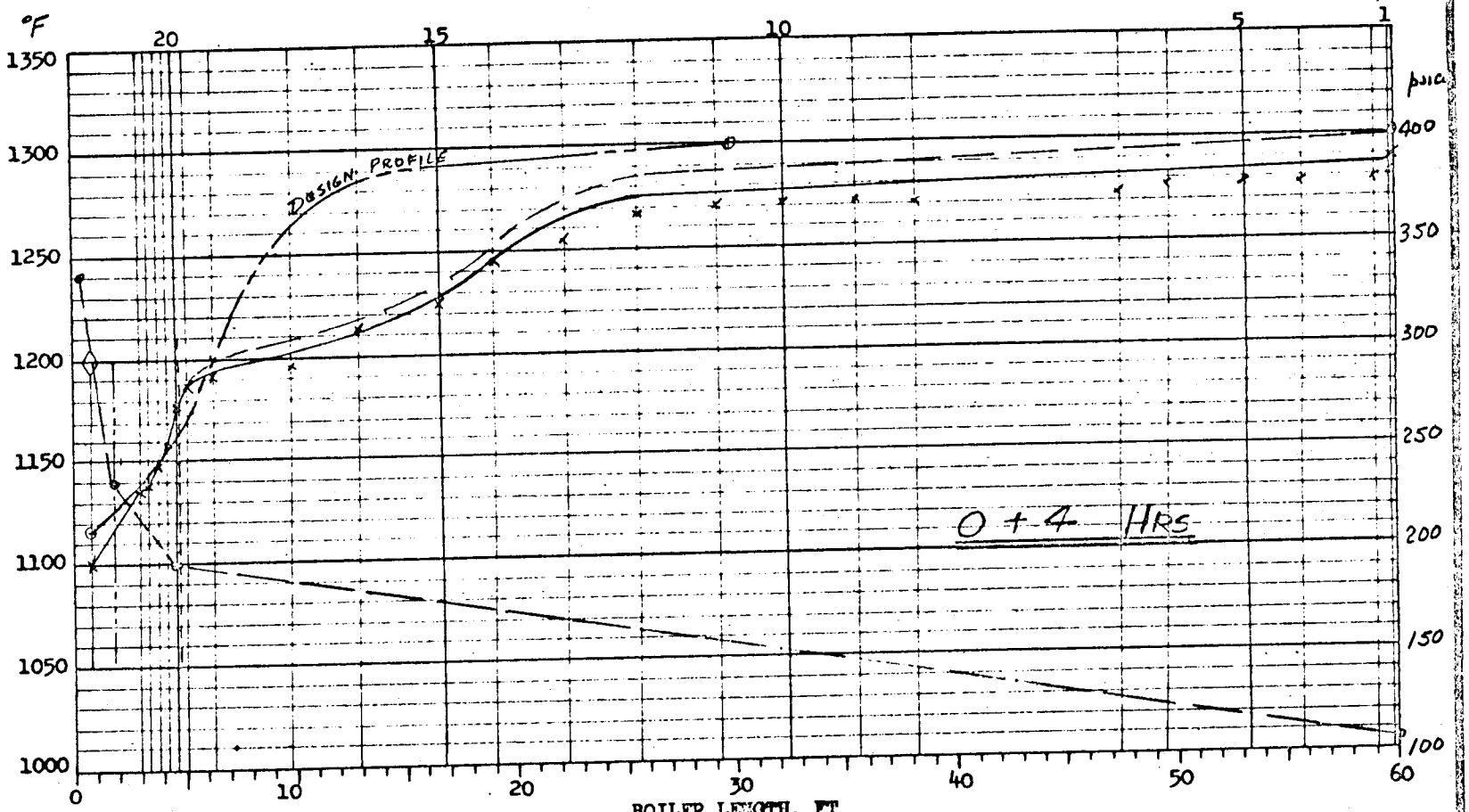
ΔP_B = 40 psi ΔP_{PH} = — psi ΔP_x = — psi

ΔP_{PL} = — psi ΔP_{UPL} = — psi

DATE 2/24/65
TIME 1600
RUN NO. 1-50

CL-4 BOILER NaK TEMPERATURE PROFILE

Fig. C-2



PLUG INSERT: #2

$W(p \times \Delta L)_{PH}$ = 1/8" x 18"

$W(p \times \Delta L)_{V}$ = 3/4" x 36"

W_N = 2250 LB/HR

T_{Nbi} = 1300 °F

T_{Nbo} = 1100 °F

ΔT_N = 200 °F

W_H = 600 LB/HR

T_{Hbi} = 390 °F

T_{Hbo} = 1220 °F

P_{Hbi} = 340 psia

P_1 = — psia

P_2 = — psia

P_{Hbo} = 105 psia

ΔP_B = 235 psi

ΔP_{PH} = — psi

ΔP_x = — psi

ΔP_{PL} = — psi

ΔP_{UPL} = — psi

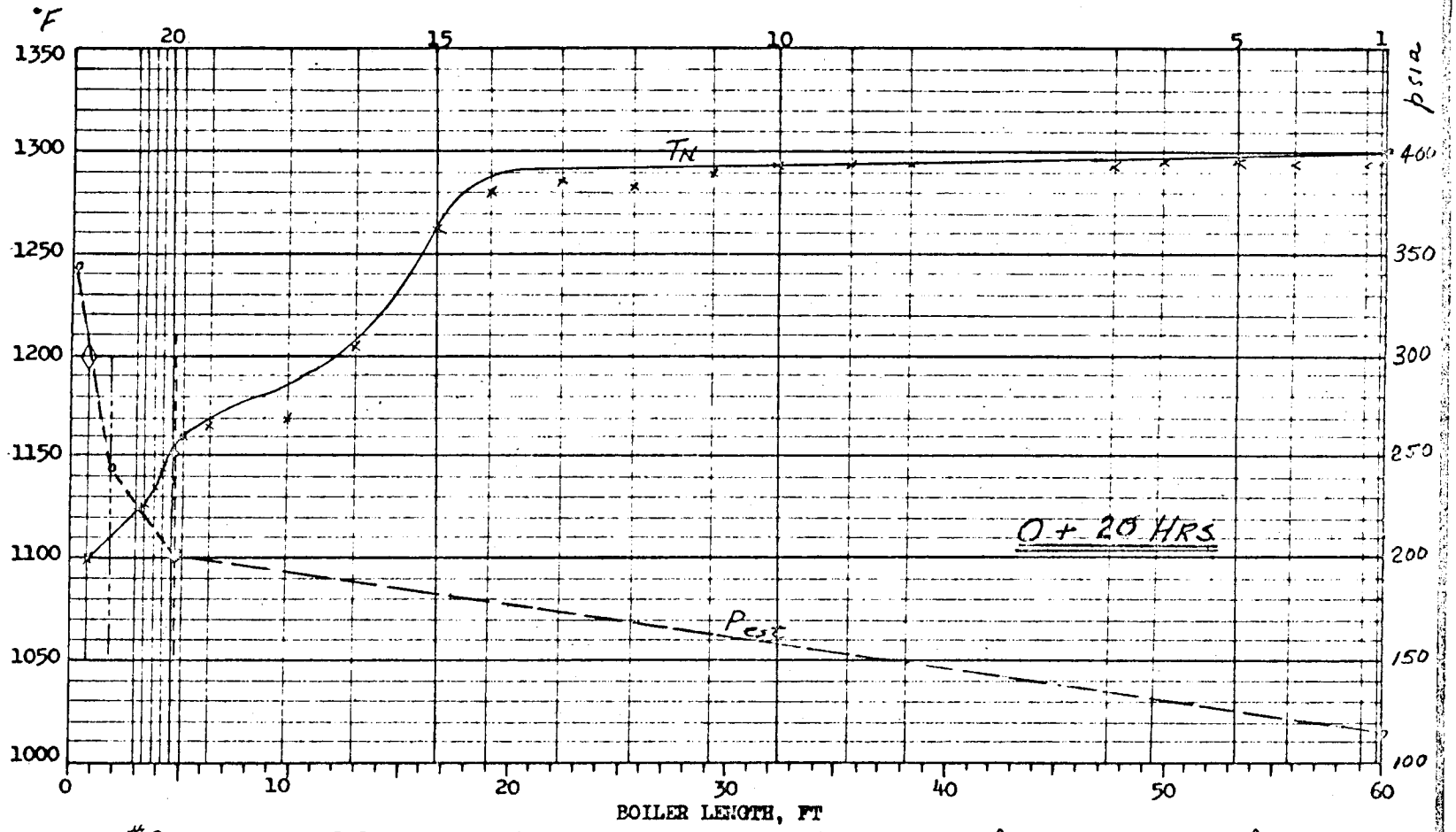
DATE 3/10/65

TIME 1400

RUN NO. 2 - 1

CL-4 BOILER NaK TEMPERATURE PROFILE

Fig. C-3



PLUG INSERT: #2
$(p \times \Delta L)_{PH}$ = 1/8" x 18"
$(p \times \Delta L)_V$ = 3/4" x 36"

W_N = 2250 LB/HR
T_{Nbi} = 1300 °F
T_{Nbo} = 1100 °F
ΔT_N = 200 °F

W_H = 600 LB/HR
T_{Hbi} = 450 °F
T_{Hbo} = 1230 °F

P_{Hbi} = 344 psia
P_1 = — psia
P_2 = — psia
P_{Hbo} = 115 psia

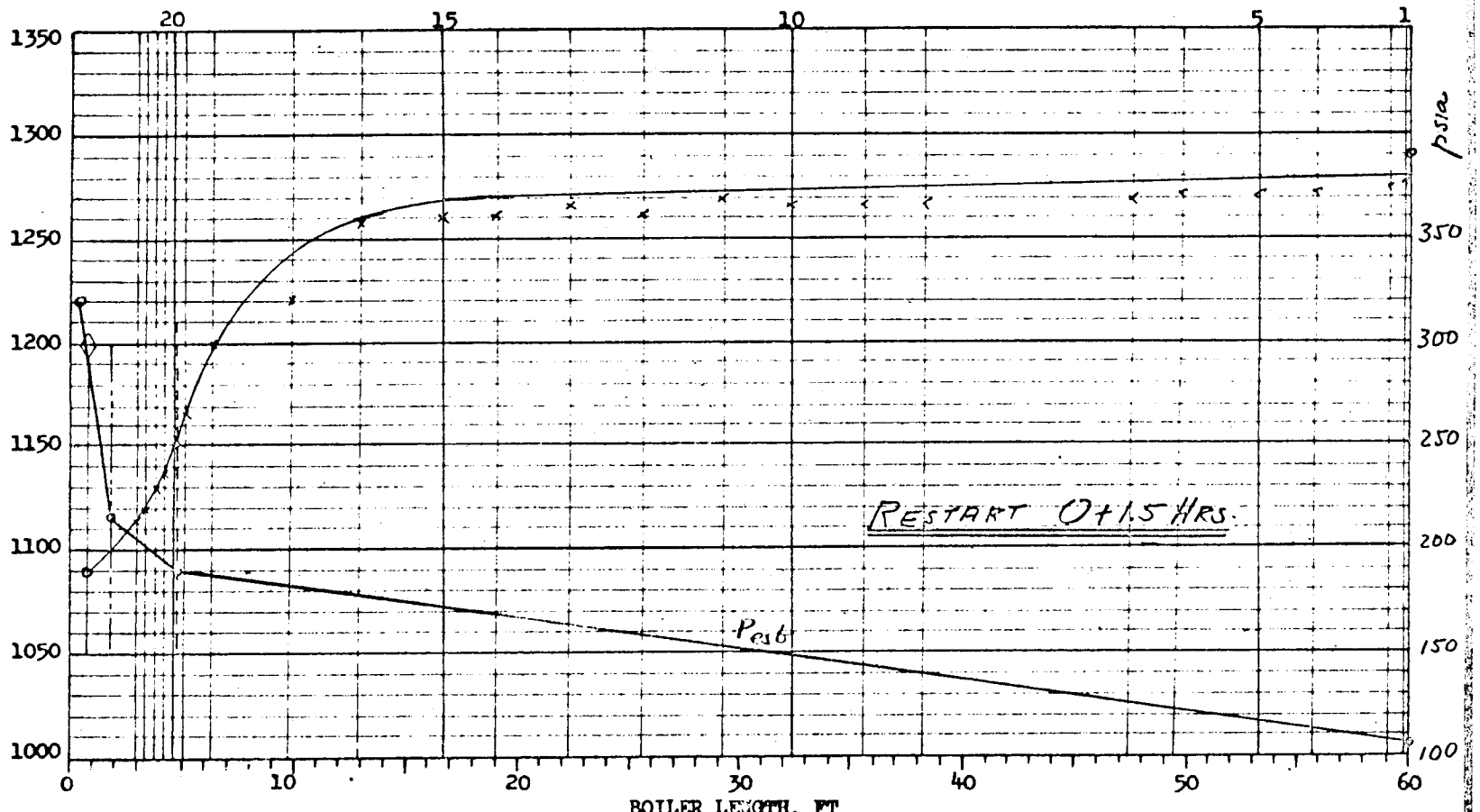
ΔP_B = 229 psi
ΔP_{PH} = — psi
ΔP_x = — psi

ΔP_{PL} = — psi
ΔP_{UPL} = — psi

DATE 3/11/65
TIME 0837
RUN NO. 2-3

CL-4 BOILER NaK TEMPERATURE PROFILE

Fig. C-4



PLUG INSERT: #2

$W(p \times \Delta L)_{PH}$ = 1/8" < 18"

$W(p \times \Delta L)_{V}$ = 3/4" < 36'

W_N = LB/HR

T_{Nbi} = 1290 °F

T_{Nbo} = 1090 °F

ΔT_N = 200 °F

W_H = 470 LB/HR

T_{Hbi} = 340 °F

T_{Hbo} = 1210 °F

P_{Hbi} = 320 psia

P_1 = — psia

P_2 = — psia

P_{Hbo} = 105 psia

ΔP_B = 215 psi

ΔP_{PH} = — psi

ΔP_x = — psi

ΔP_{PL} = — psi

ΔP_{UPL} = — psi

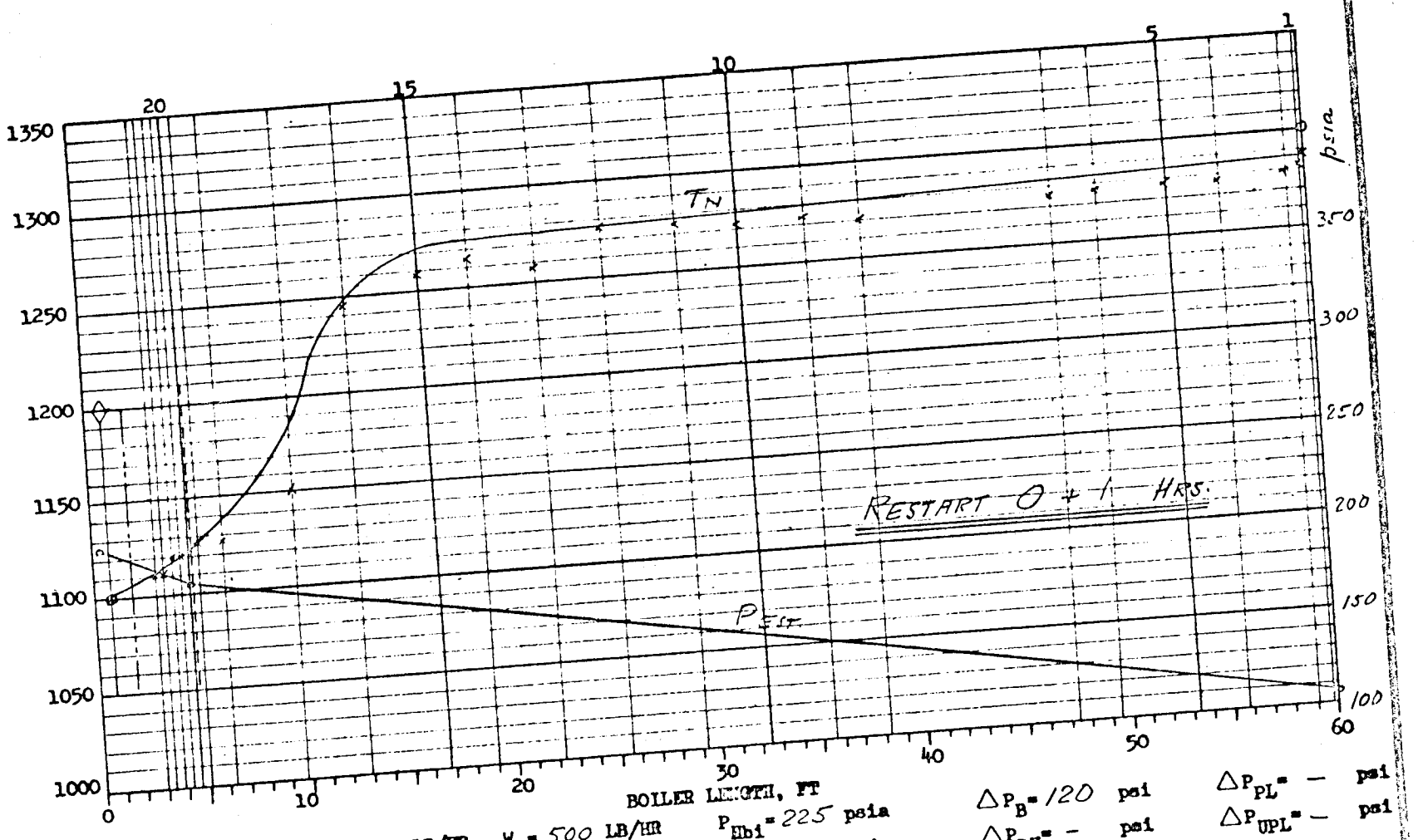
DATE 3/17/65

TIME 1100

RUN NO. 3-1

CL-4 BOILER NaK TEMPERATURE PROFILE

Fig. C-5



PLUG INSERT: #1

$(p \times \Delta L)_{PH}$ = 3/4" x 21"

$(p \times \Delta L)_{V}$ = 3/4" x 36"

W_N = LB/HR

T_{Nbi} = 1300 °F

T_{Nbo} = 1100 °F

ΔT_N = 200 °F

W_H = 500 LB/HR

T_{Hbi} = 380 °F

T_{Hbo} = 1215 °F

P_{Hbi} = 225 psia

P_1 = — psia

P_2 = — psia

P_{Hbo} = 105 psia

ΔP_B = 120 psi

ΔP_{PH} = — psi

ΔP_x = — psi

ΔP_{PL} = — psi

ΔP_{UPL} = — psi

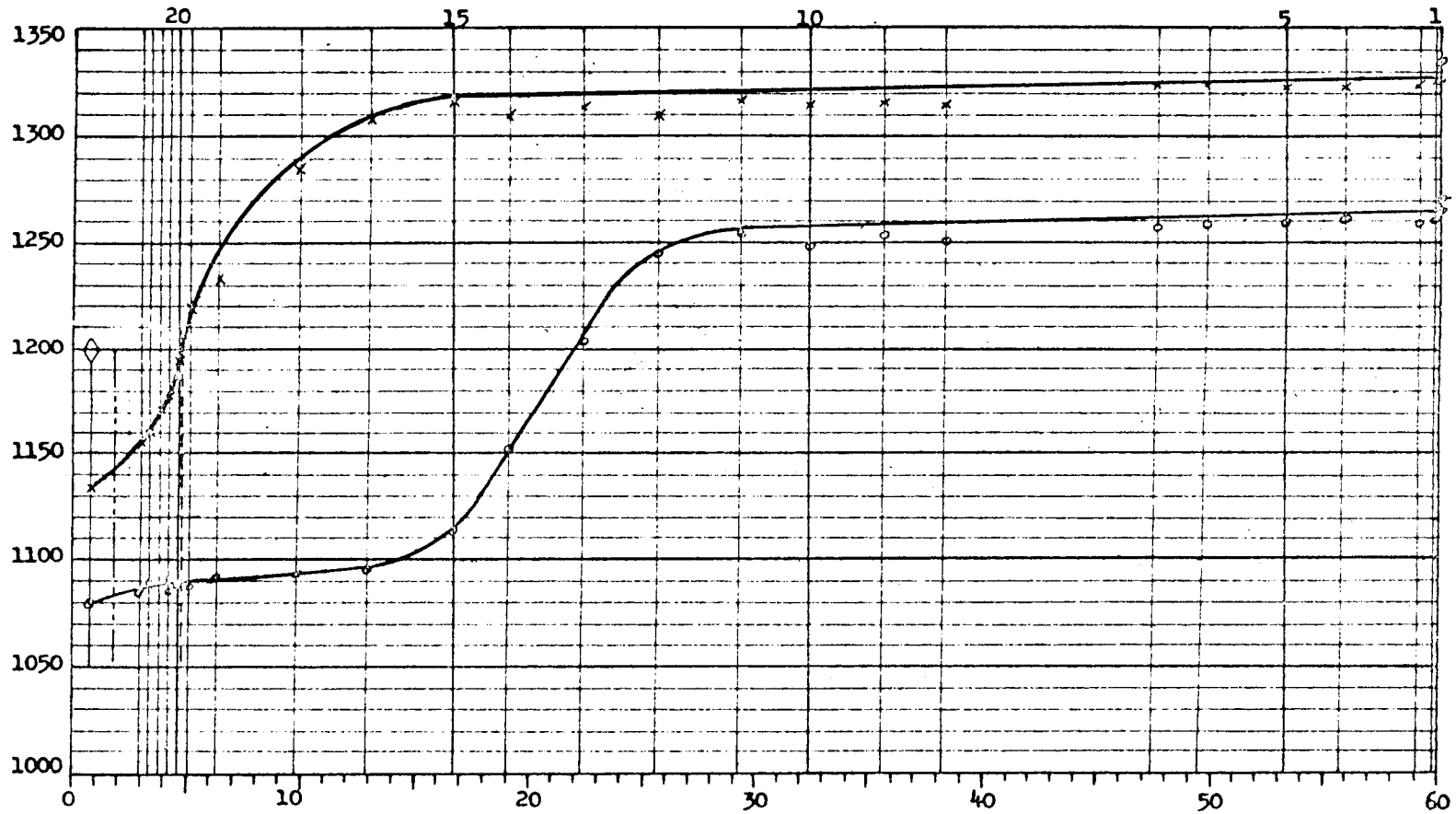
DATE 3/30/65

TIME 1120

RUN NO. 4-1

CL-4 BOILER NaK TEMPERATURE PROFILE

Fig. C-6



PLUG INSERT: No PLUG INS $W_N = \frac{2040}{1930}$ LB/HR $W_H = \frac{535}{511}$ LB/HR $P_{Hbi} = \frac{343 \pm 29}{312 \pm 12}$ psia $\Delta P_B = \frac{111}{96}$ psi $\Delta P_{PL} =$ — psi

$(p \times \Delta L)_{PH} =$ $(p \times \Delta L)_{W} =$ } $0 \times 57''$ $T_{Nbi} = \frac{1335}{1270}$ °F $T_{Hbi} = \frac{450}{450}$ °F $P_1 =$ — psia $\Delta P_{PH} =$ - psi $\Delta P_{UPL} =$ — psi

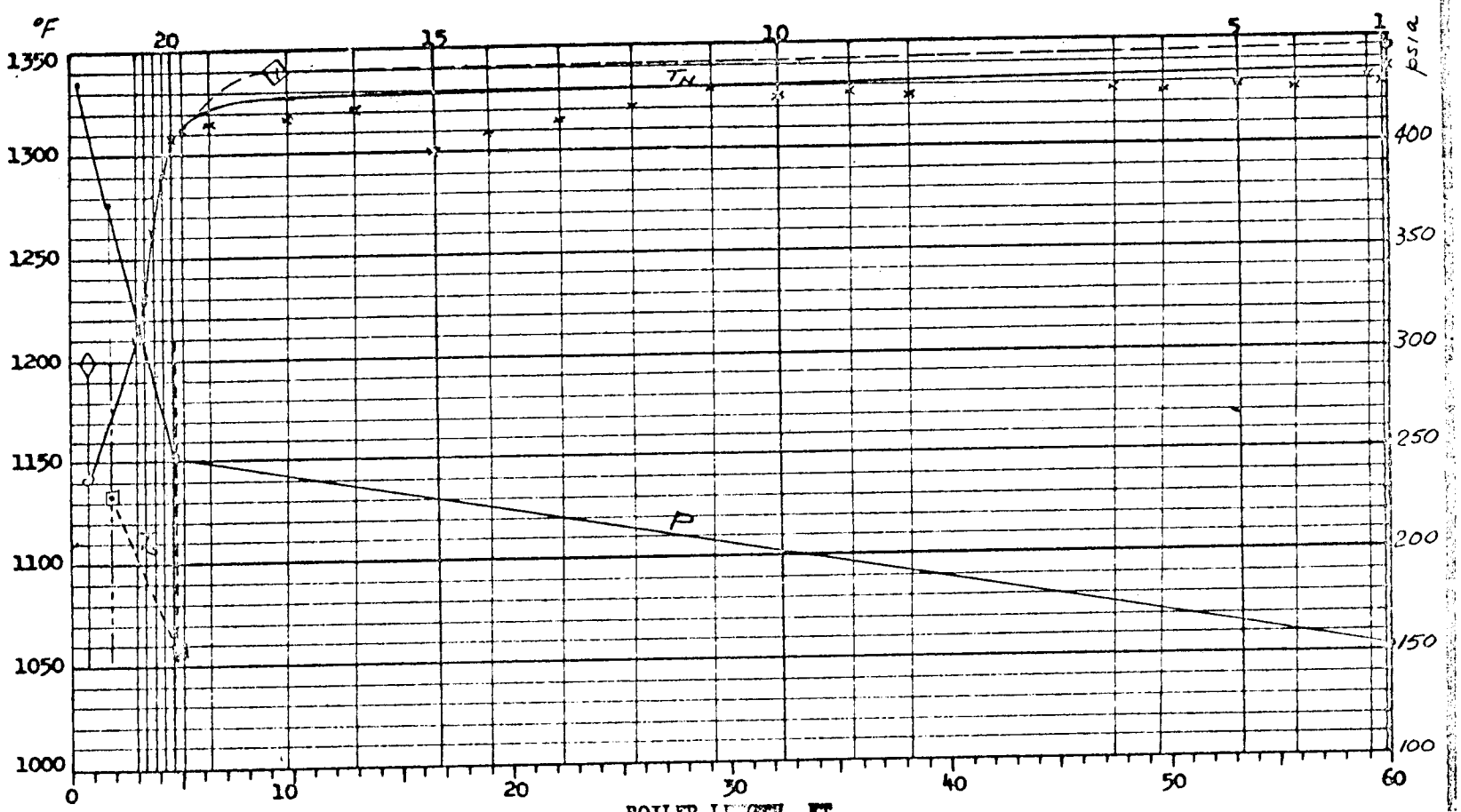
$T_{Nbo} = \frac{1135}{1180}$ °F $T_{Hbo} = \frac{1260}{1200}$ °F $P_2 =$ — psia $\Delta P_x =$ — psi

$\Delta T_N = \frac{200}{190}$ °F $P_{Hbo} = \frac{232 \pm 21}{211 \pm 10}$ psia

DATE 5/26/65
TIME 1355/1555
RUN NO. 9-3/6

CL-4 BOILER NaK TEMPERATURE PROFILE

Fig. C-7



PLUG INSERT: #3

$M\ (p \times \Delta L)_{PH}$ = 1/8" x 15"

$W\ (p \times \Delta L)_{v}$ = 3/4" x 36"

W_N = 2025 LB/HR

T_{NBi} = 1345 °F

T_{NBo} = 1142 °F

ΔT_N = 203 °F

W_H = 492 LB/HR

T_{HBi} = 500 °F

T_{HBo} = 1260 °F

P_{HBi} = 435 psia

P_1 = 378 psia

P_2 = 252 psia

P_{HBo} = 152 psia

ΔP_B = 283 psi

ΔP_{PH} = 57 psi

ΔP_X = 126 psi

ΔP_{PL} = 183 psi

ΔP_{UPL} = 100 psi

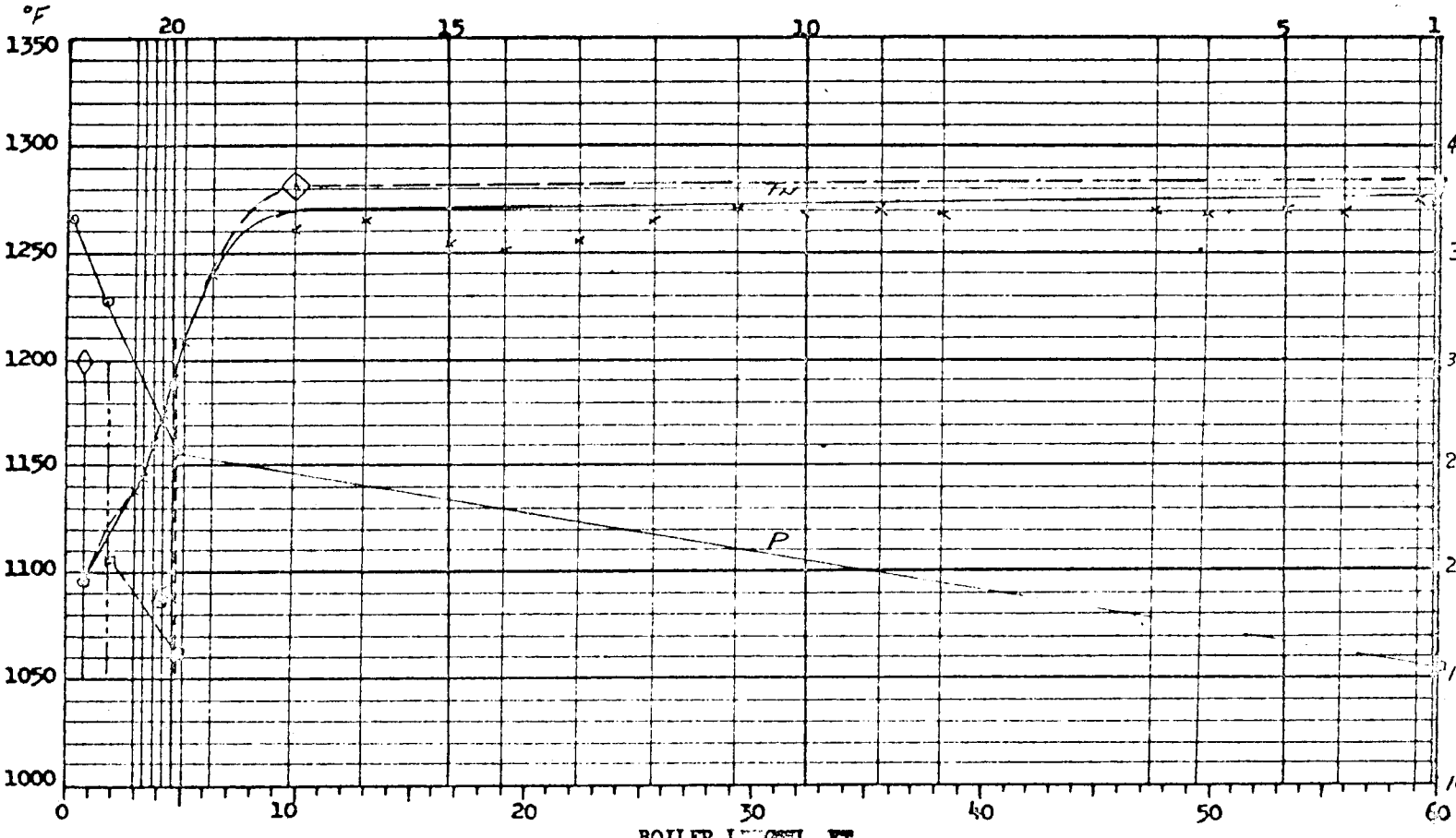
DATE 4/11/65

TIME 1820

RUN NO. 5-16

CL-4 BOILER NaK TEMPERATURE PROFILE

Fig. C-8



PLUG INSERT: #3

$M(p \times \Delta L)_{PH}$ = 1/8" x 15"

$W(p \times \Delta L)_{v}$ = 3/4" x 36"

W_N = 2055 LB/HR

T_{Nbi} = 1285 °F

T_{Nbo} = 1095 °F

ΔT_N = 190 °F

W_H = 506 LB/HR

T_{Hbi} = 500 °F

T_{Hbo} = 1205 °F

P_{Hbi} = 365 psia

P_1 = 328 psia

P_2 = 258 psia

P_{Hbo} = 154 psia

ΔP_B = 211 psi

ΔP_{PH} = 37 psi

ΔP_x = 70 psi

ΔP_{PL} = 107 psi

ΔP_{UPL} = 104 psi

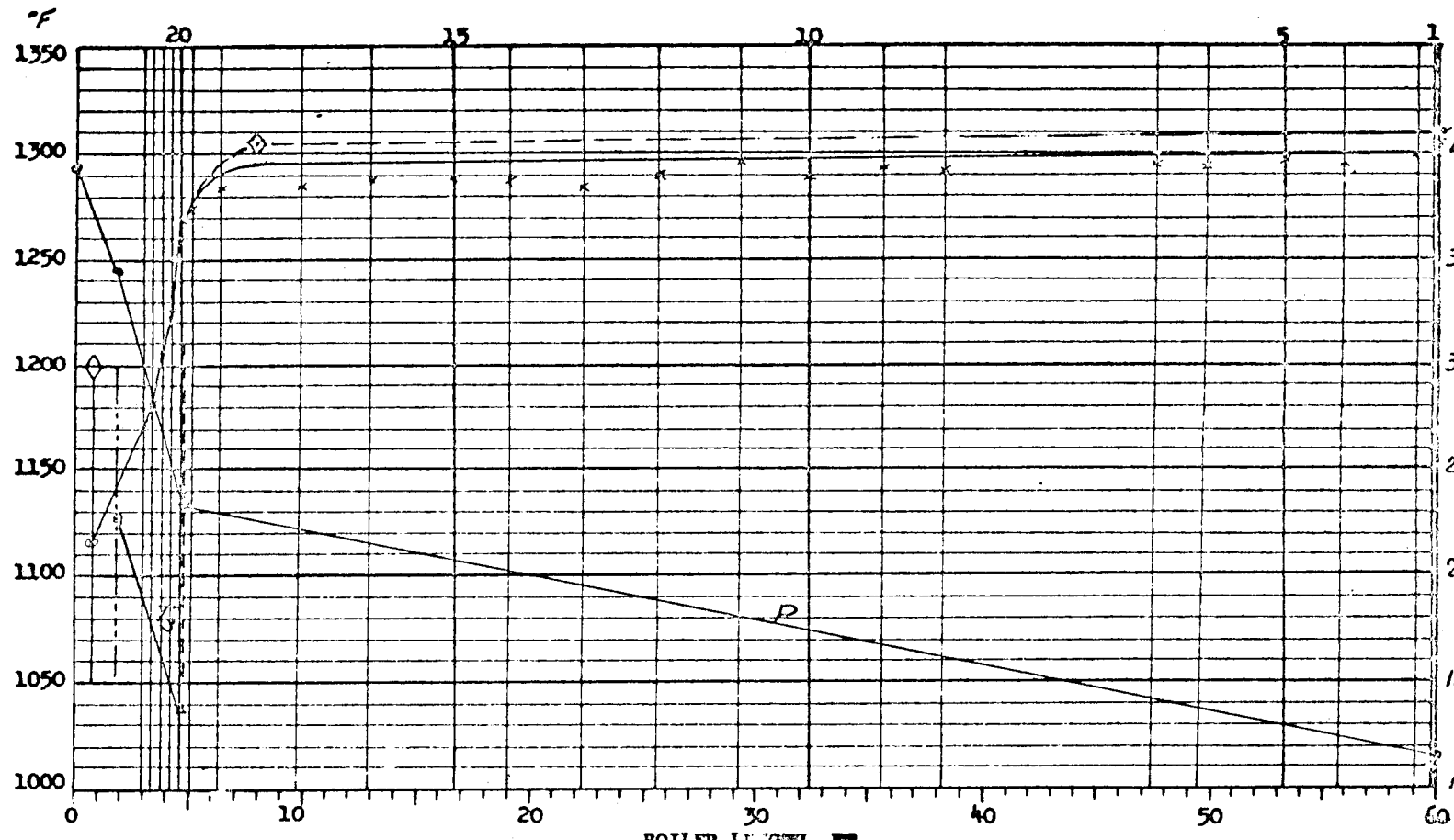
CL-4 BOILER NaK TEMPERATURE PROFILE

DATE 4/11/65

TIME 2000

RUN NO. 5-17

Fig. C-9



PLUG INSERT:

$M(p \times \Delta L)_{PH}$ = 1/8" < 15"

$(p \times \Delta L)_{v}$ = 3/4" < 36

W_N = 2040 LB/HR

T_{Nbi} = 1310 °F

T_{Nbo} = 1125 °F

ΔT_N = 185 °F

W_H = 500 LB/HR

T_{Hbi} = 500 °F

T_{Hbo} = 1230 °F

P_{Hbi} = 395 psia

P_1 = 345 psia

P_2 = 235 psia

P_{Hbo} = 116 psia

ΔP_B = 279 psi

ΔP_{PH} = 50 psi

ΔP_x = 110 psi

ΔP_{PL} = 160 psi

ΔP_{UPL} = 111 psi

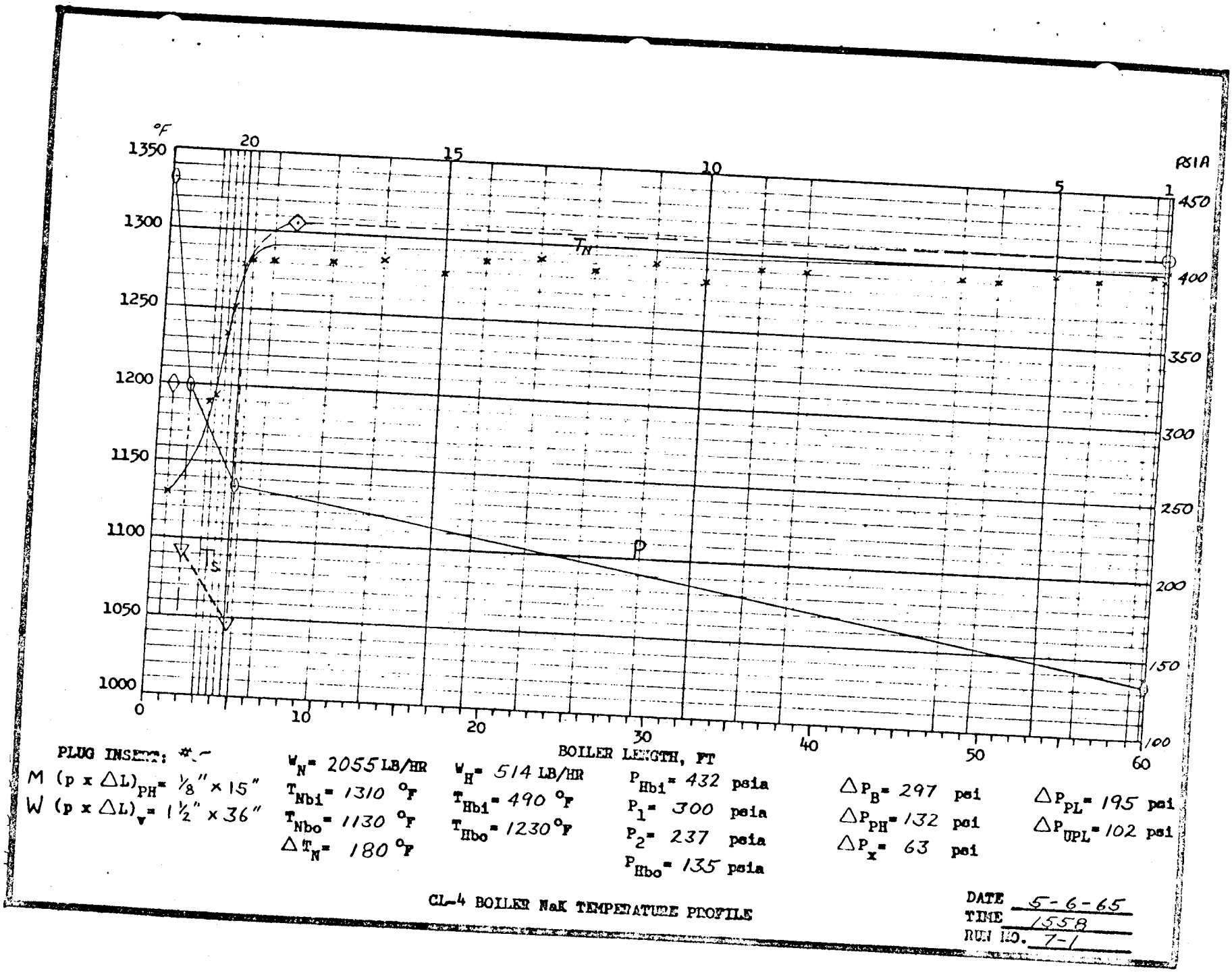
DATE 4/11/65

TIME 2155

RUN NO. 5-18

CL-4 BOILER NaK TEMPERATURE PROFILE

Fig. C-10



PLUG INSERT: #7

M $(p \times \Delta L)_{PH}$ = 1/8" x 15"

W $(p \times \Delta L)_{V}$ = 1 1/2" x 36"

W_N = 2055 LB/HR
T_{Nbi} = 1310 °F
T_{Nbo} = 1130 °F
ΔT_N = 180 °F

W_H = 514 LB/HR
T_{Hbi} = 490 °F
T_{Hbo} = 1230 °F

P_{Hbi} = 432 psia
P_1 = 300 psia
P_2 = 237 psia
P_{Hbo} = 135 psia

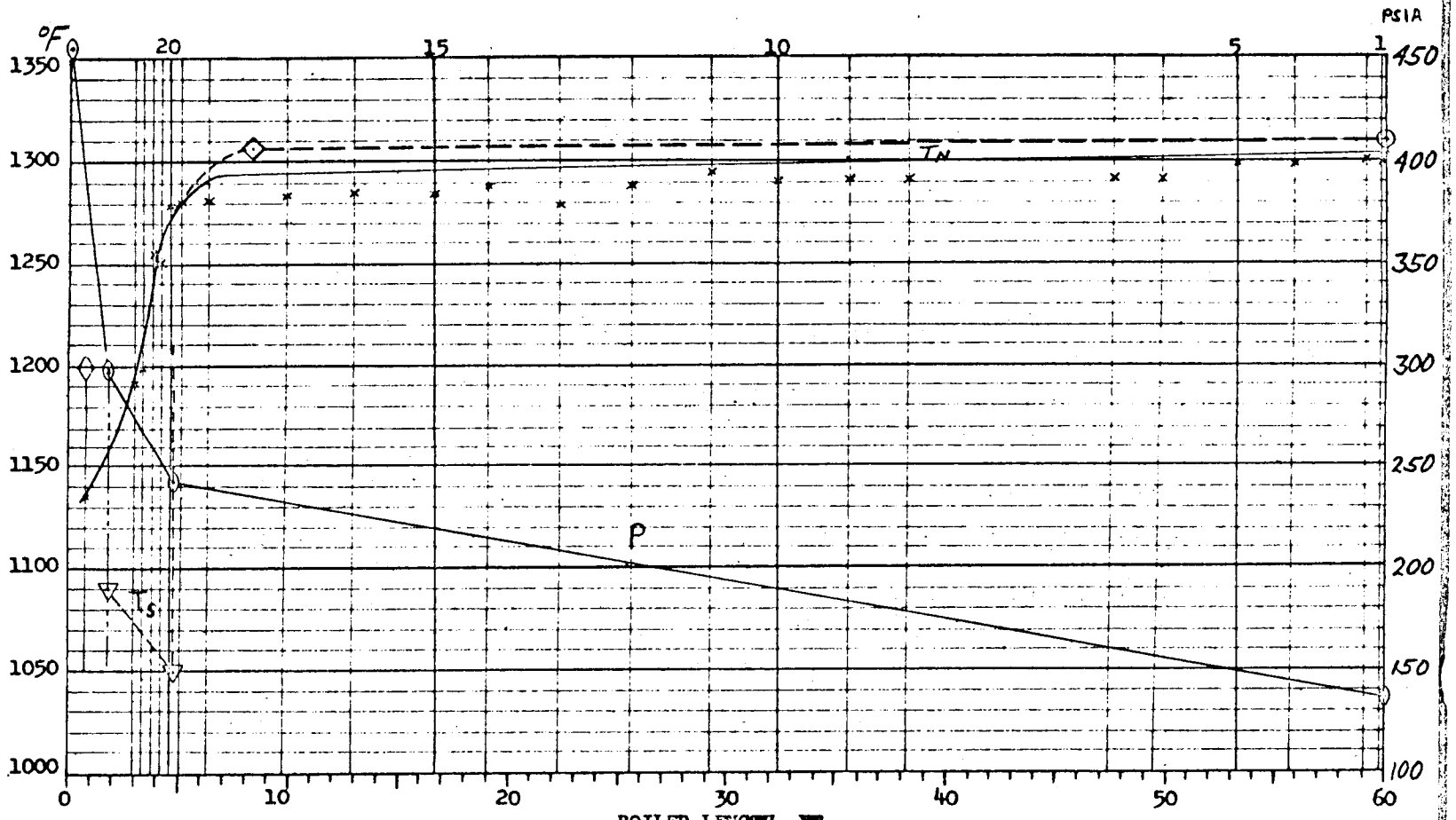
ΔP_B = 297 psi
ΔP_{PH} = 132 psi
ΔP_x = 63 psi

ΔP_{PL} = 195 psi
ΔP_{UPL} = 102 psi

CL-4 BOILER NaK TEMPERATURE PROFILE

DATE 5-6-65
TIME 1558
RUN NO. 7-1

Fig. C-11



PLUG INSERT: #5

M $(p \times \Delta L)_{PH}$ = 1/8" x 15"

W $(p \times \Delta L)_{v}$ = 1½" x 36"

W_N = 2050 LB/HR

T_{Nbi} = 1310 °F

T_{Nbo} = 1134 °F

ΔT_N = 176 °F

W_H = 497 LB/HR

T_{Hbi} = 500 °F

T_{Hbo} = 1230 °F

P_{Hbi} = 455 psia

P_1 = 298 psia

P_2 = 242 psia

P_{Hbo} = 137 psia

ΔP_B = 318 psi

ΔP_{PH} = 157 psi

ΔP_v = 56 psi

ΔP_{PL} = 213 psi

ΔP_{UPL} = 105 psi

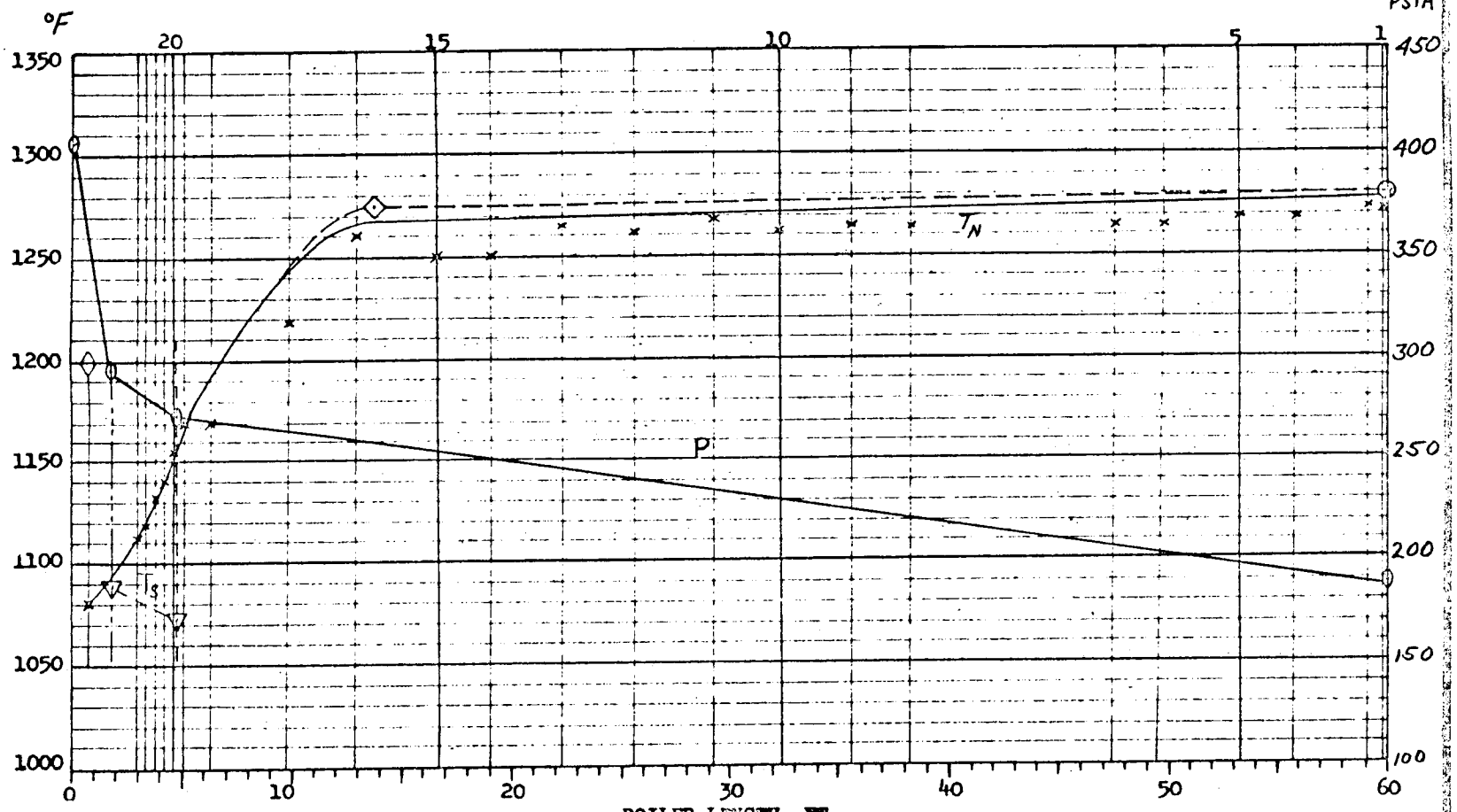
DATE 5-6-65

TIME 1654

RUN NO. 7-2

CL-4 BOILER NaK TEMPERATURE PROFILE

Fig. C-12



PLUG INSERT: #5

M $(p \times \Delta L)_{PH}$ = 1/8" × 15"

W $(p \times \Delta L)_{V}$ = 1½" × 36"

W_N = 1830 LB/HR

T_{Nbi} = 1280 °F

T_{Nbo} = 1080 °F

ΔT_N = 200 °F

W_H = 497 LB/HR

T_{Hbi} = 510 °F

T_{Hbo} = 1210 °F

P_{Hbi} = 406 psia

P_1 = 296 psia

P_2 = 274 psia

P_{Hbo} = 188 psia

ΔP_B = 218 psi

ΔP_{PH} = 110 psi

ΔP_x = 22 psi

ΔP_{PL} = 132 psi

ΔP_{UPL} = 86 psi

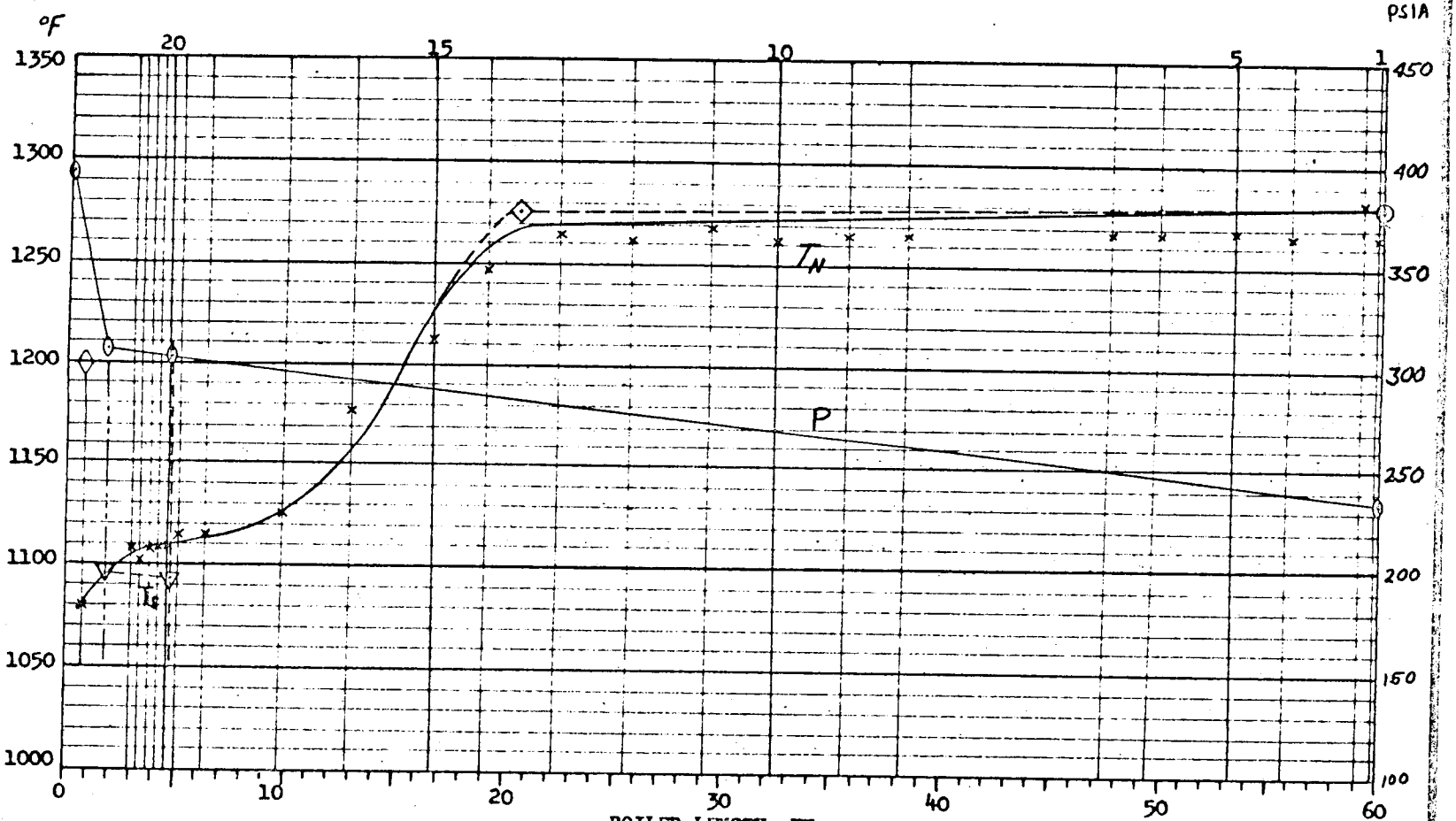
DATE 5-6-65

TIME 2010

RUN NO. 7-3

CL-4 BOILER MAX TEMPERATURE PROFILE

Fig. C-13



PLUG INSERT: #5

M $(p \times \Delta L)_{PH}$ = ⅛" × 15"

W $(p \times \Delta L)_v$ = 1½" × 36"

W_N = 1800 LB/HR
T_{Nbi} = 1280 °F
T_{Nbo} = 1080 °F
ΔT_N = 200 °F

W_H = 497 LB/HR
T_{Hbi} = 505 °F
T_{Hbo} = 1210 °F

P_{Hbi} = 393 psia
P_1 = 307 psia
P_2 = 303 psia
P_{Hbo} = 235 psia

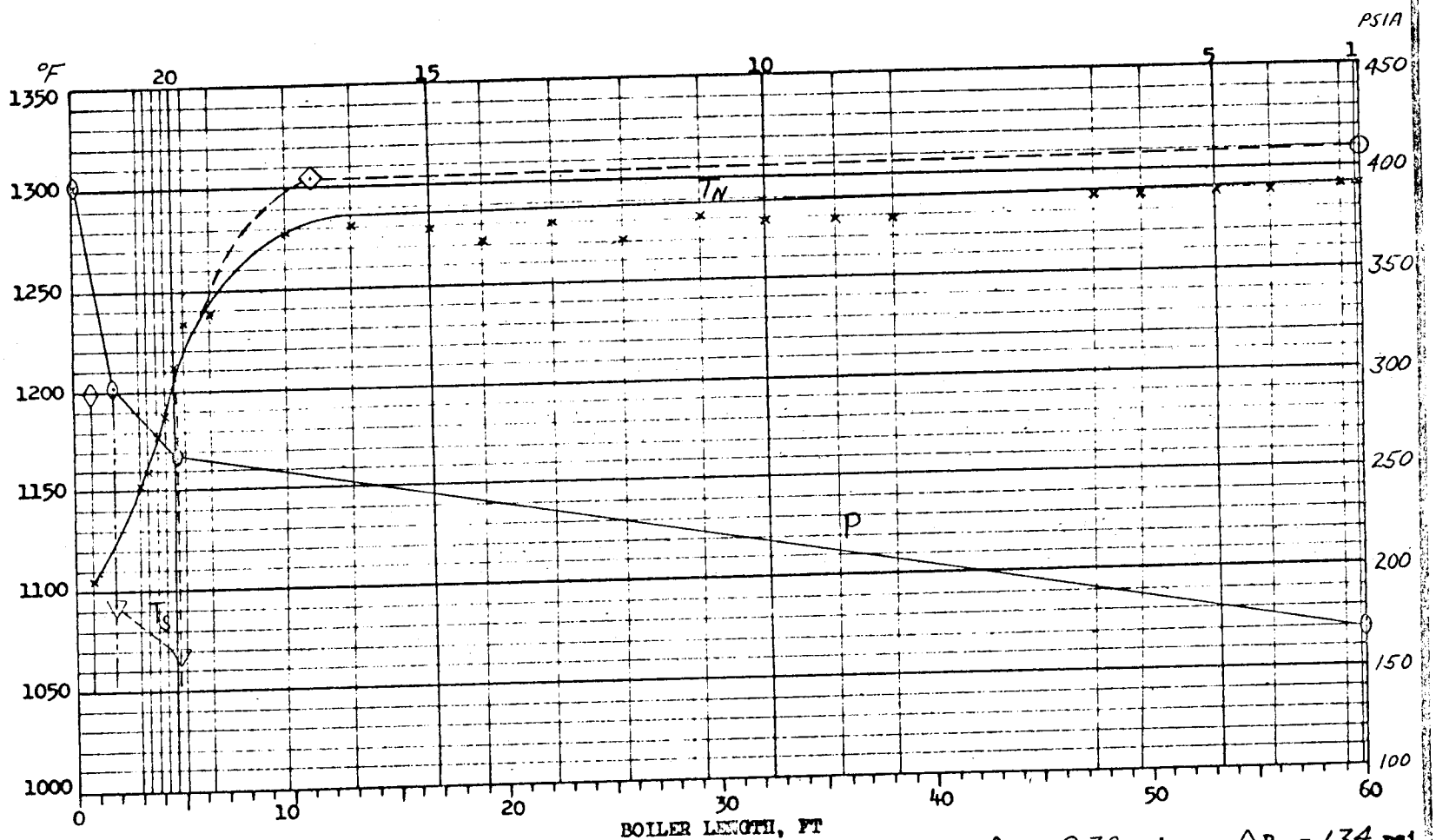
ΔP_B = 158 psi
ΔP_{PH} = 86 psi
ΔP_x = 4 psi

ΔP_{PL} = 90 psi
ΔP_{UPL} = 68 psi

DATE 5-6-65
TIME 2110
RUN NO. 7-4

CL-4 BOILER MaK TEMPERATURE PROFILE

Fig. C-14



PLUG INSERT: #6

$W\ (p \times \Delta L)_{PH}$ = 1/8" × 15"

$W\ (p \times \Delta L)_{v}$ = 1½" × 36"

W_N = 2055 LB/HR

T_{Nbi} = 1309 °F

T_{Nbo} = 1104 °F

ΔT_N = 205 °F

W_H = 500 LB/HR

T_{Hbi} = 430 °F

T_{Hbo} = 1220 °F

P_{Hbi} = 402 psia

P_1 = 302 psia

P_2 = 268 psia

P_{Hbo} = 170 psia

ΔP_B = 232 psi

ΔP_{PH} = 100 psi

ΔP_x = 34 psi

ΔP_{PL} = 134 psi

ΔP_{UPL} = 98 psi

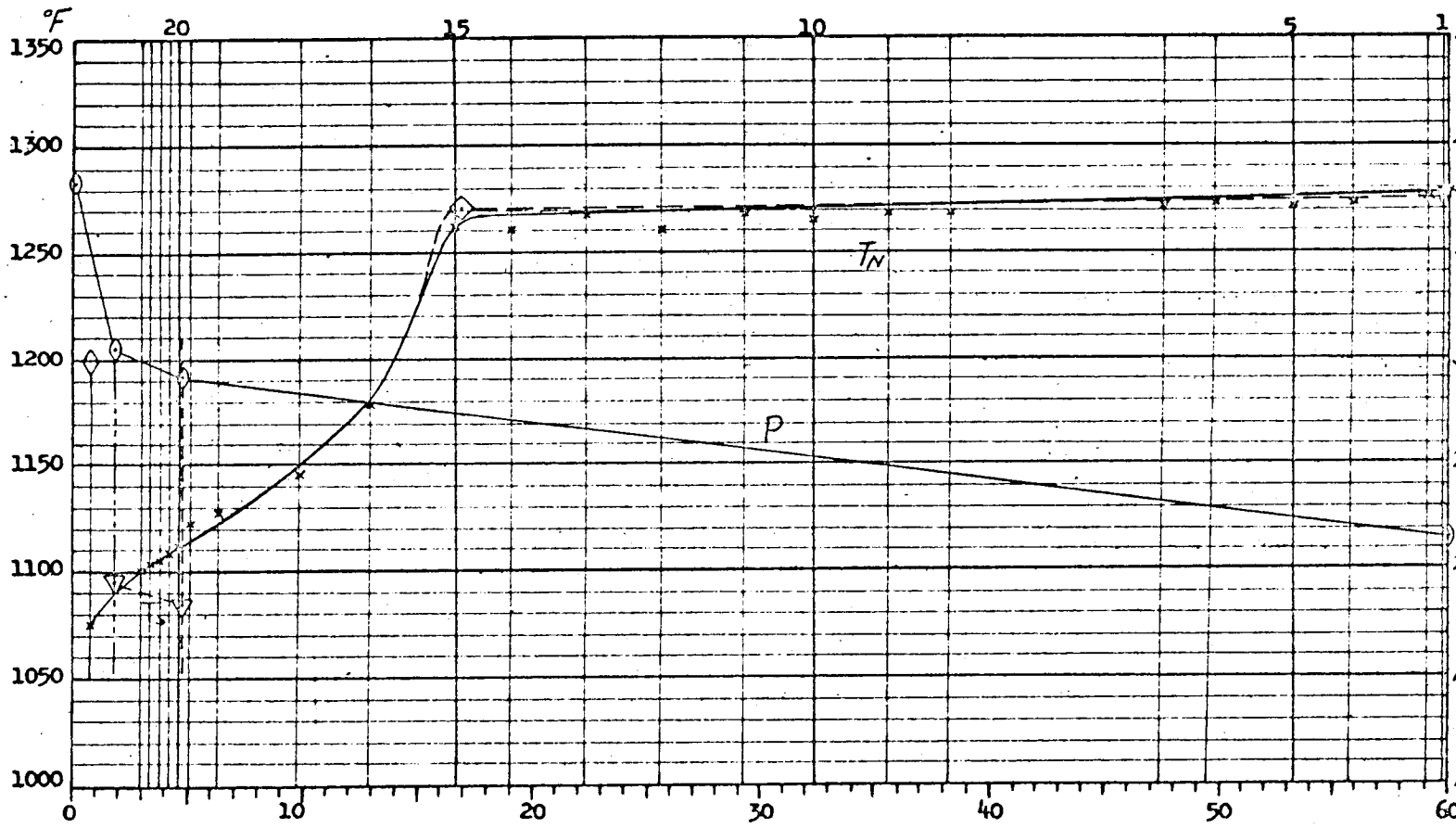
DATE 5-12-65

TIME 1055

RUN NO. 8-1

CL-4 BOILER NaK TEMPERATURE PROFILE

Fig. C-15



PLUG INSERT: #6

W_N = 1770 LB/HR

W_H = 503 LB/HR

P_{Hbi} = 383 psia

ΔP_B = 168 psi

ΔP_{PL} = 91 psi

$W\ (p \times \Delta L)_{PH}$ = ⅛" × 15"

T_{Nbi} = 1275 °F

T_{Hbi} = 520 °F

P_1 = 305 psia

ΔP_{PH} = 78 psi

ΔP_{UPL} = 77 psi

$W\ (p \times \Delta L)_w$ = 1½" × 36"

T_{Nbo} = 1075 °F

T_{Hbo} = 1210 °F

P_2 = 292 psia

ΔP_x = 13 psi

ΔT_N = 200 °F

P_{Nbo} = 215 psia

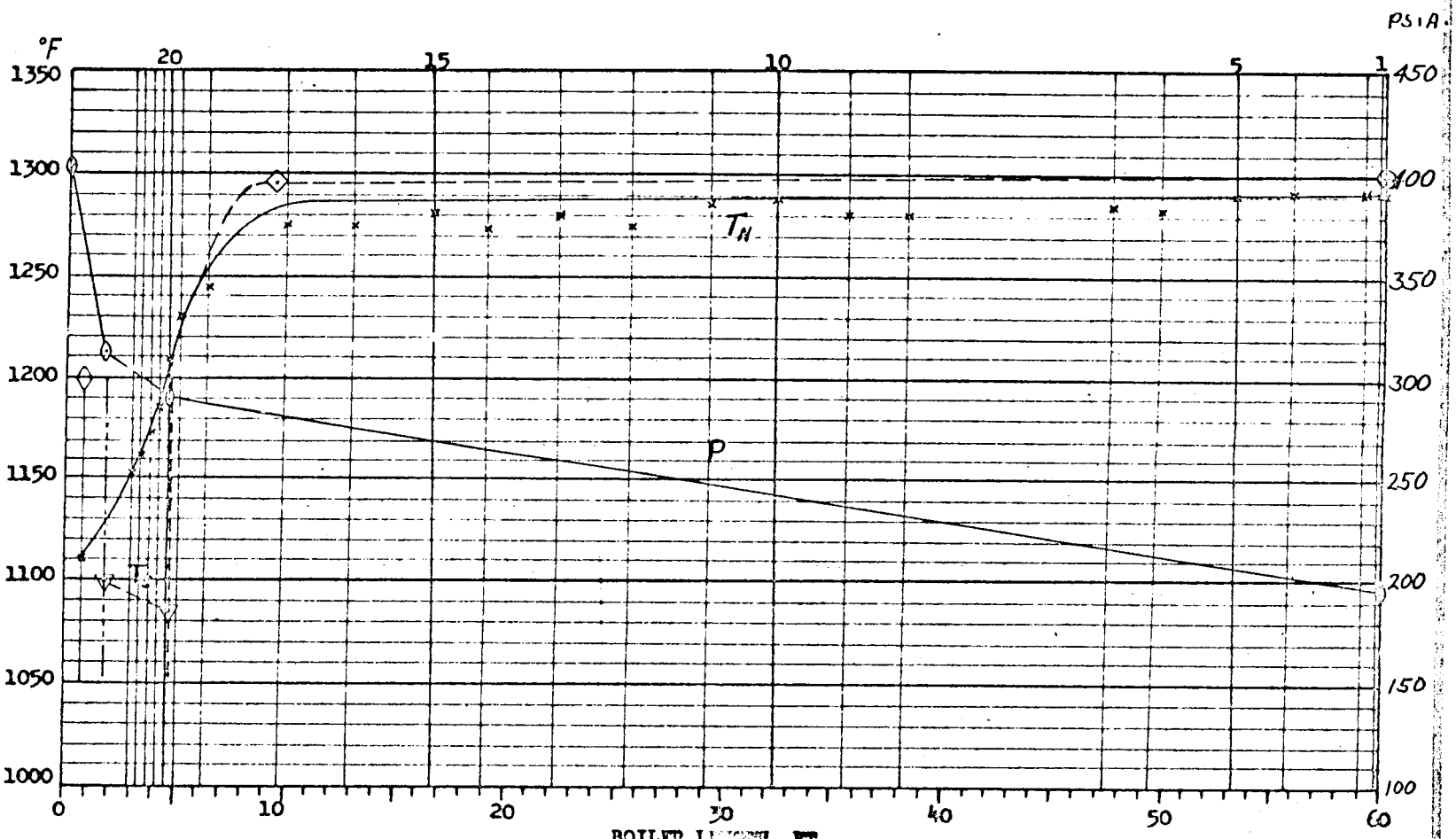
DATE 5-13-65

TIME 1045

RUN NO. 8-2

CL-4 BOILER NaK TEMPERATURE PROFILE

Fig. C-15



PLUG INSERT: #6

W (p x ΔL)$_{PH}$ = 1/8" x 15"

W (p x ΔL)$_{v}$ = 1½" x 36"

W_N = 2055 LB/HR

T_{Nbi} = 1300 °F

T_{Nbo} = 1110 °F

ΔT_N = 190 °F

W_H = 500 LB/HR

T_{Hbi} = 430 °F

T_{Hbo} = 1225 °F

P_{Nbi} = 403 psia

P_1 = 312 psia

P_2 = 290 psia

P_{Nbo} = 196 psia

ΔP_B = 207 psi

ΔP_{PH} = 91 psi

ΔP_x = 22 psi

ΔP_{PL} = 113 psi

ΔP_{UPL} = 94 psi

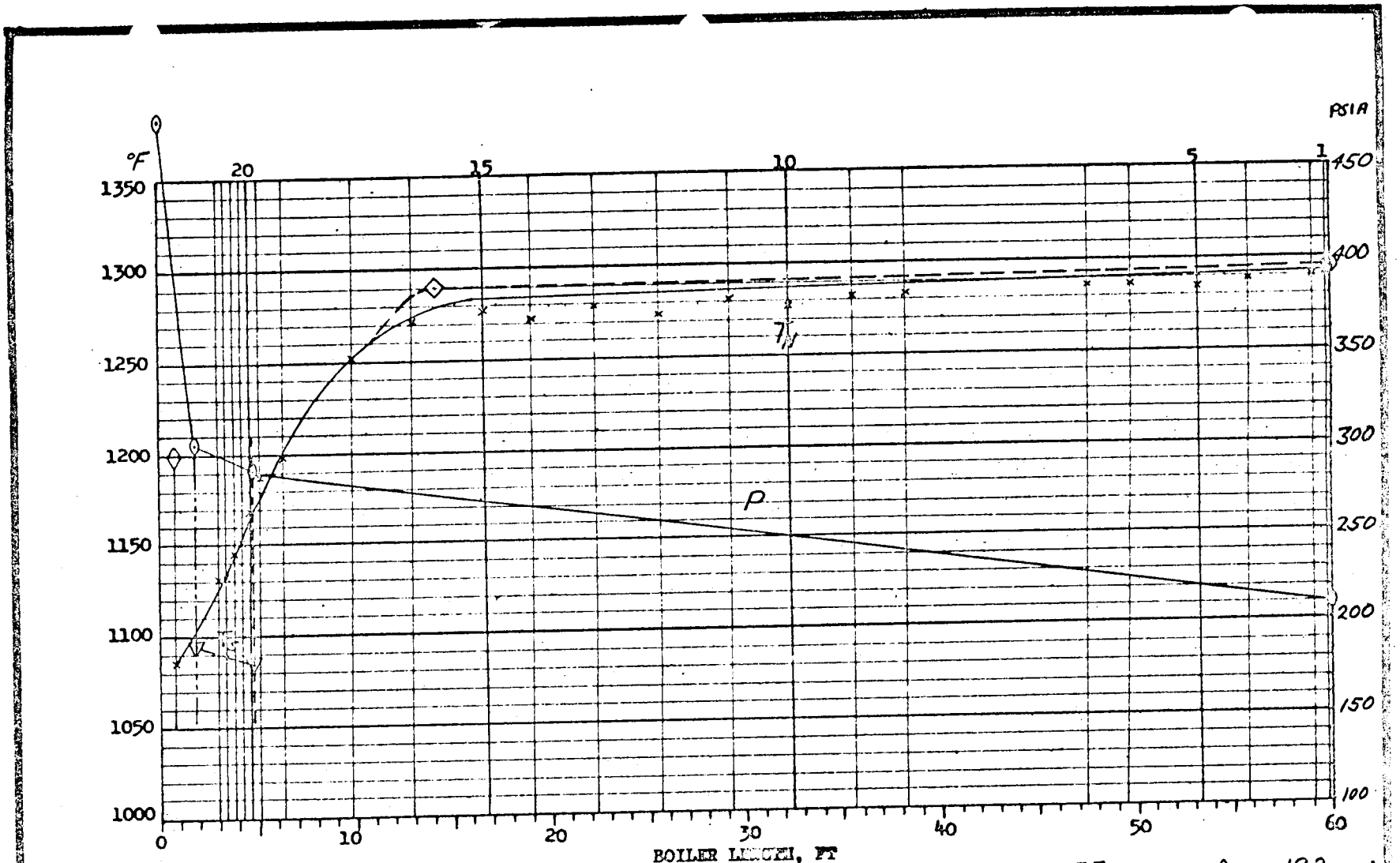
CL-4 BOILER MaX TEMPERATURE PROFILE

DATE 5-12-65

TIME 1320

RUN NO. 8-3

Fig. C-17



PLUG INSERT: #6

W (p x ΔL)$_{PH}$ = ⅛" x 15"

W (p x ΔL)$_{V}$ = 1½" x 36"

W_N = 1770 LB/HR

T_{Nbi} = 1295 °F

T_{Nbo} = 1085 °F

ΔT_N = 210 °F

W_H = 483 LB/HR

T_{Hbi} = 520 °F

T_{Hbo} = 1225 °F

P_{Hbi} = 483 psia

P_1 = 306 psia

P_2 = 291 psia

P_{Hbo} = 210 psia

ΔP_B = 273 psi

ΔP_{PH} = 177 psi

ΔP_x = 15 psi

ΔP_{PL} = 192 psi

ΔP_{UPL} = 81 psi

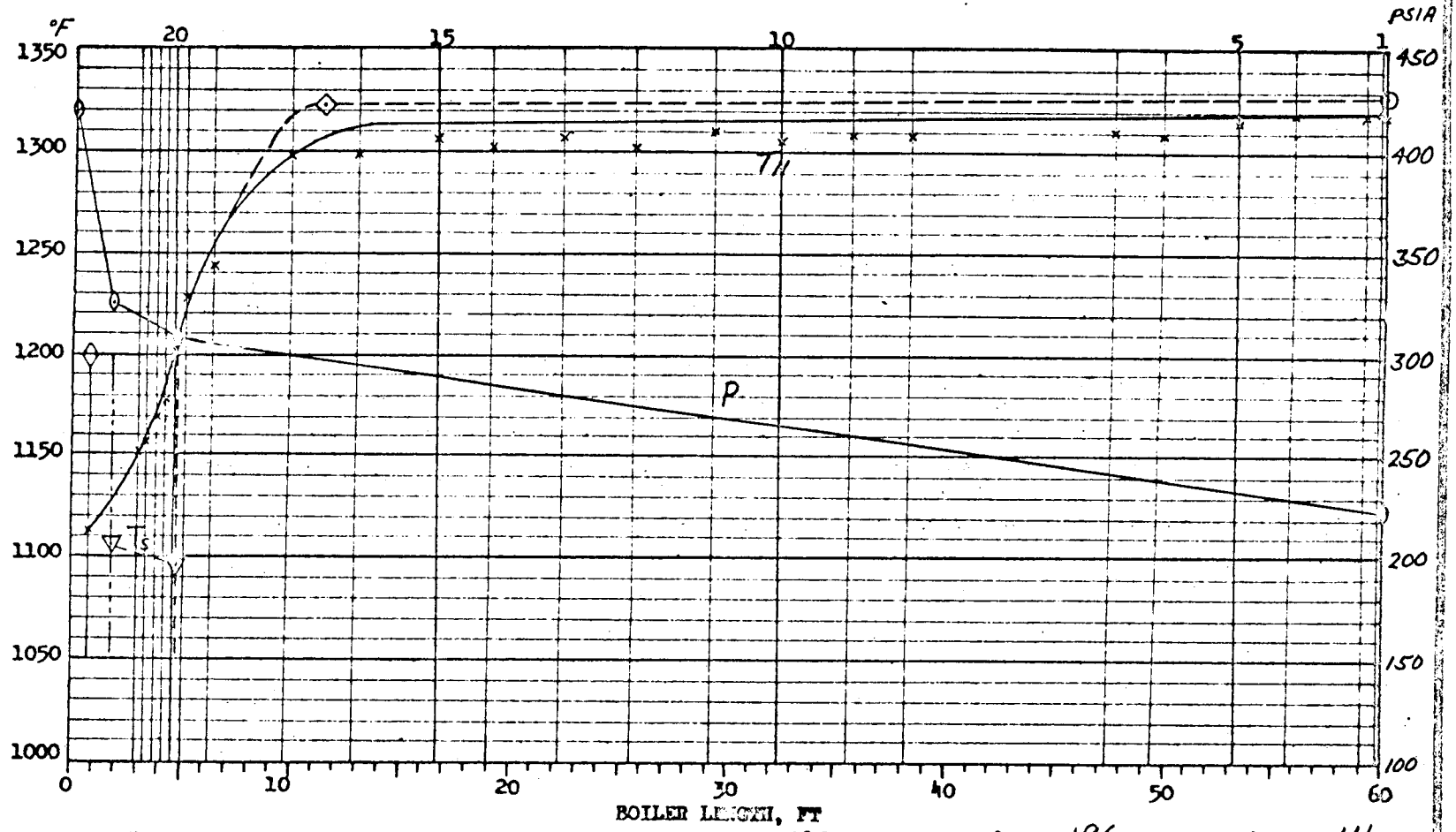
DATE 5-13-65

TIME 1150

RUN NO. 8-4

CL-4 BOILER NaK TEMPERATURE PROFILE

Fig. C-18



PLUG INSERT: *6

W (p x ΔL)$_{PH}$ = ⅛" x 15"

W (p x ΔL)$_{v}$ = 1½" x 36"

W_N = 1770 LB/HR

T_{Hbi} = 1328 °F

T_{Hbo} = 1112 °F

ΔT_N = 216 °F

W_H = 507 LB/HR

T_{Hbi} = 520 °F

T_{Hbo} = 1250 °F

P_{Hbi} = 420 psia

P_1 = 325 psia

P_2 = 309 psia

P_{Hbo} = 224 psia

ΔP_B = 196 psi

ΔP_{PH} = 95 psi

ΔP_x = 16 psi

ΔP_{PL} = 111 psi

ΔP_{UPL} = 85 psi

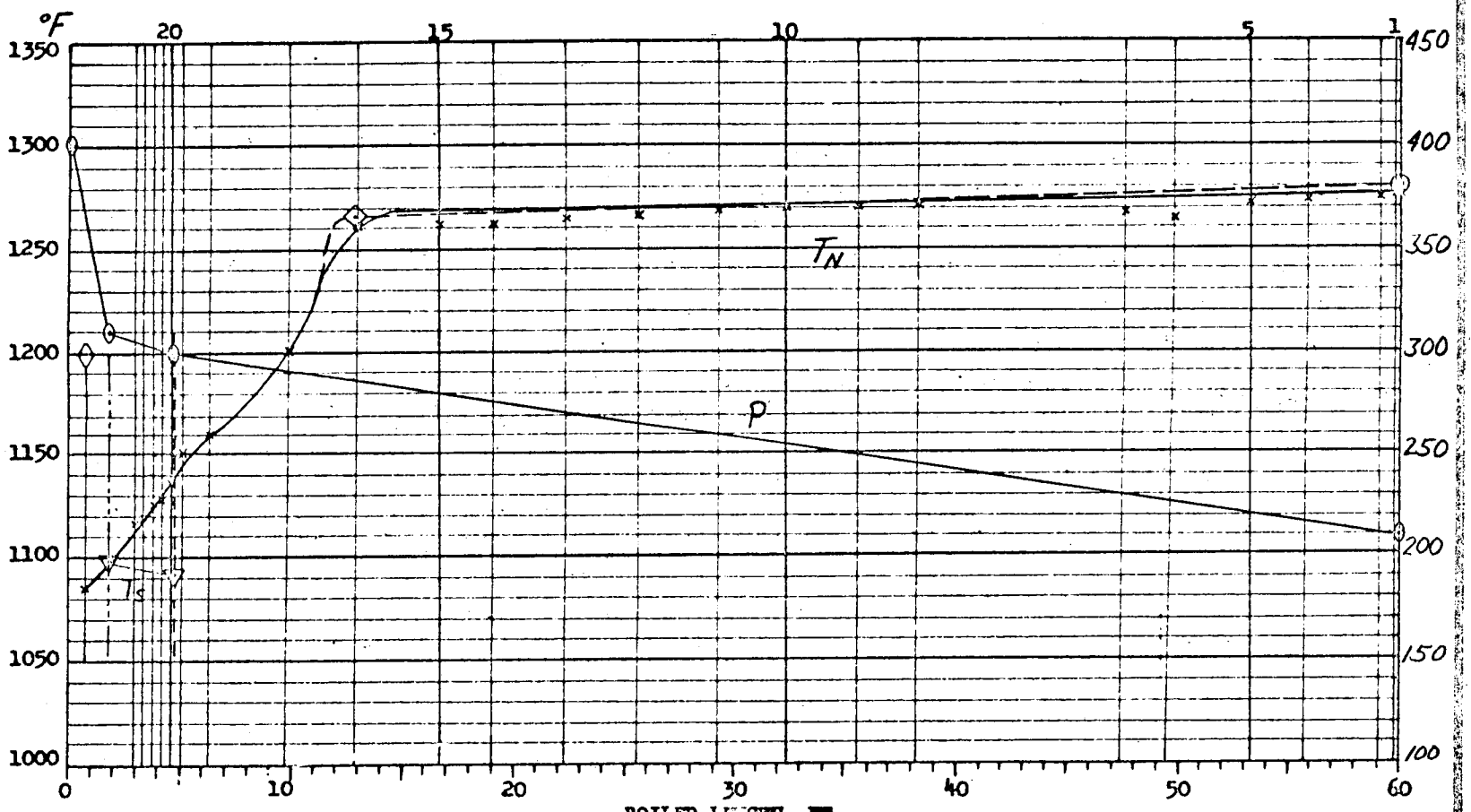
CL-4 BOILER MaX TEMPERATURE PROFILE

DATE 5-13-65

TIME 1330

RUN NO. 8-5

Fig. C-19



PLUG INSERT: #6
W (p x ΔL)$_{PH}$ = 1/8" x 15"
W (p x ΔL)$_{v}$ = 1½" x 36"

W_N = 1950 LB/HR
T_{Nbi} = 1280 °F
T_{Nbo} = 1085 °F
ΔT_N = 195 °F

W_H = 499 LB/HR
T_{Hbi} = 516 °F
T_{Hbo} = 1210 °F

P_{Hbi} = 401 psia
P_1 = 310 psia
P_2 = 300 psia
P_{Hbo} = 210 psia

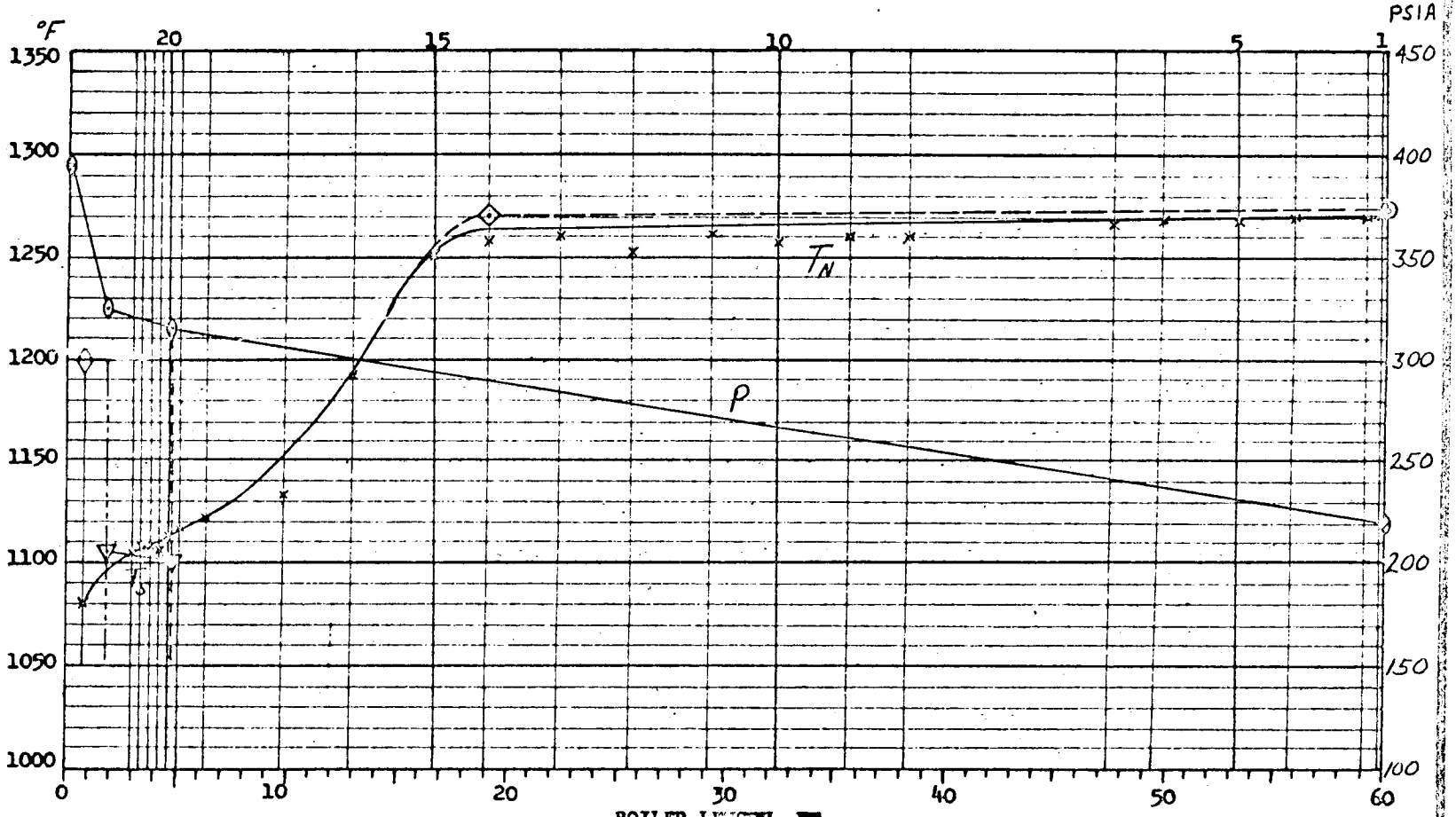
ΔP_B = 191 psi
ΔP_{PH} = 91 psi
ΔP_x = 10 psi

ΔP_{PL} = 101 psi
ΔP_{UPL} = 90 psi

DATE 5-14-65
TIME 1245
RUN NO. 8-7

CL-4 BOILER WaK TEMPERATURE PROFILE

Fig. C-20



PLUG INSERT: #6

W (p x ΔL)$_{PH}$ = 1/8" x 15"

W (p x ΔL)$_{v}$ = 1 1/2" x 36"

W_N = 2070 LB/HR

T_{Hbi} = 1275 °F

T_{Hbo} = 1080 °F

ΔT_N = 195 °F

W_H = 522 LB/HR

T_{Hbi} = 435 °F

T_{Hbo} = 1210 °F

P_{Hbi} = 395 psia

P_1 = 325 psia

P_2 = 316 psia

P_{Hbo} = 220 psia

ΔP_B = 175 psi

ΔP_{PH} = 70 psi

ΔP_x = 9 psi

ΔP_{PL} = 79 psi

ΔP_{UPL} = 96 psi

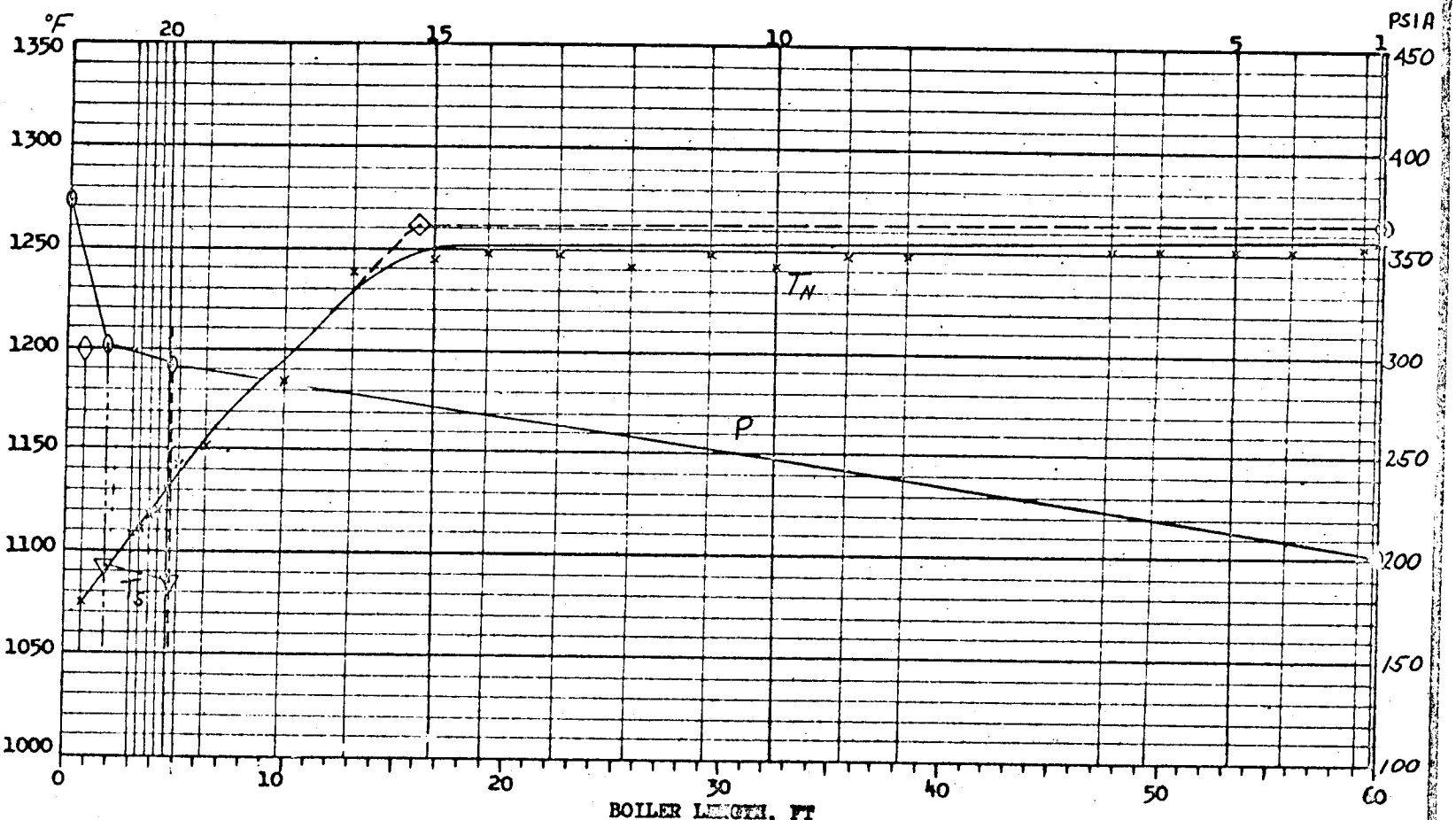
DATE 5-18-65

TIME 1505

RUN NO. 8-11

CL-4 BOILER NaK TEMPERATURE PROFILE

Fig. C-21



PLUG INSERT: #6

W (p x ΔL)$_{PH}$ = 1/8" x 15"

W (p x ΔL)$_{v}$ = 1½" x 36"

W_N = 2055 LB/HR

T_{Nbi} = 1265 °F

T_{Nbo} = 1075 °F

ΔT_N = 190 °F

W_H = 492 LB/HR

T_{Hbi} = 435 °F

T_{Hbo} = 1195 °F

P_{Hbi} = 373 psia

P_1 = 301 psia

P_2 = 292 psia

P_{Hbo} = 201 psia

ΔP_B = 172 psi

ΔP_{PH} = 72 psi

ΔP_x = 9 psi.

ΔP_{PL} = 81 psi

ΔP_{UPL} = 91 psi

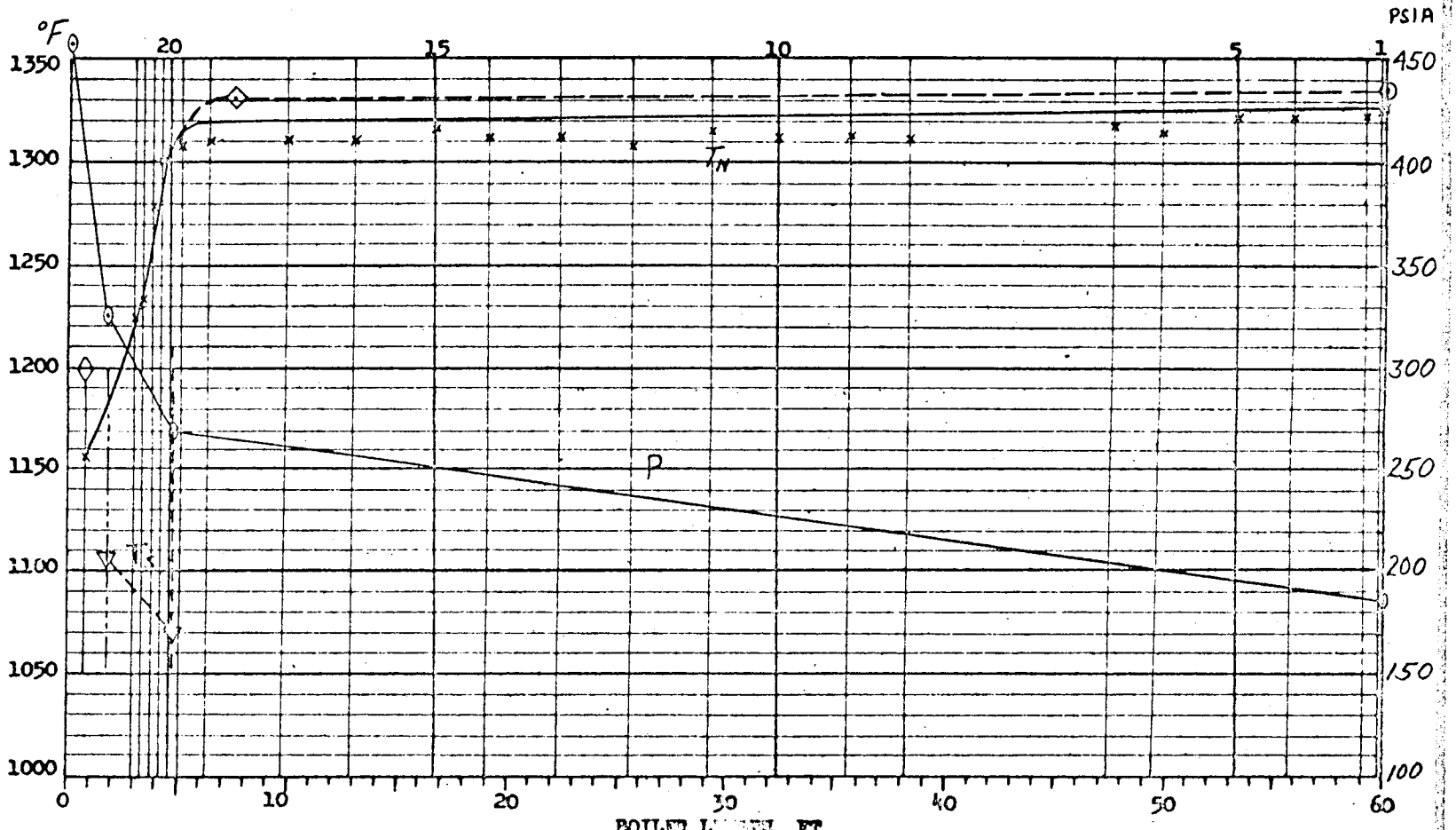
CL-4 BOILER MAX TEMPERATURE PROFILE

DATE 5-19-65

TIME 1050

RUN NO. B-12

Fig. C-22



PLUG INSERT: #6

$W\ (p \times \Delta L)_{PH}$ = ⅛" x 15"

$W\ (p \times \Delta L)_{V}$ = 1½" x 36"

W_N = 2055 LB/HR

T_{Nbi} = 1335 °F

T_{Nbo} = 1155 °F

ΔT_N = 180 °F

W_H = 480 LB/HR

T_{Hbi} = 435 °F

T_{Hbo} = 1250 °F

P_{Ebi} = 458 psia

P_1 = 326 psia

P_2 = 270 psia

P_{Ebo} = 186 psia

ΔP_B = 272 psi

ΔP_{PH} = 132 psi

ΔP_x = 56 psi

ΔP_{PL} = 188 psi

ΔP_{UPL} = 84 psi

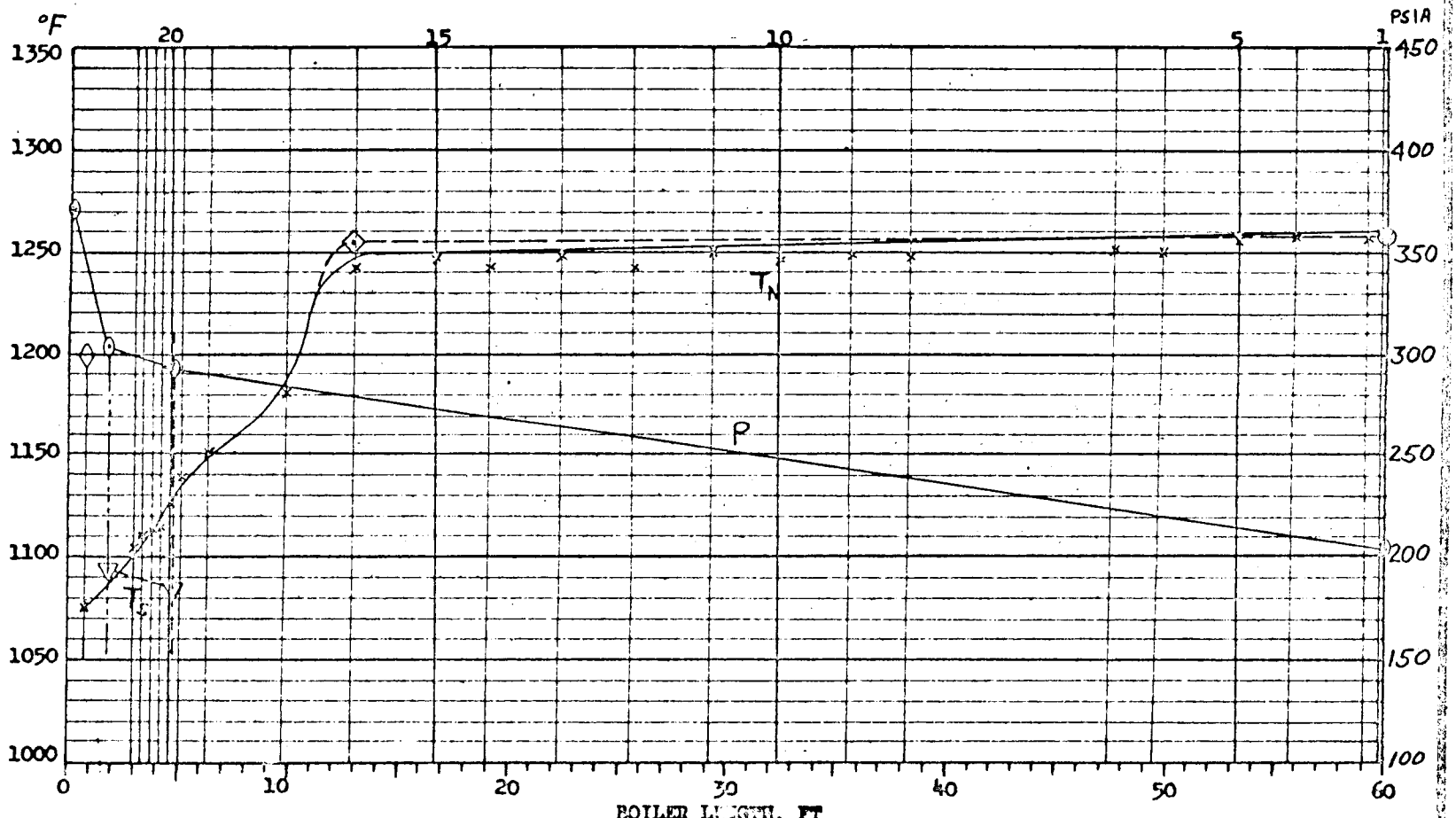
DATE 5-19-65

TIME 1245

RUN NO. 6-13

CL-4 BOILER NOZ. TEMPERATURE PROFILE

Fig. C-23



PLUG INSERT: #6

W (p x ΔL)$_{PH}$ = ⅛" x 15"

W (p x ΔL)$_{v}$ = 1½" x 36"

W_N = 2055 LB/HR

T_{Nbi} = 1258 °F

T_{Nbo} = 1076 °F

ΔT_N = 182 °F

W_H = 497 LB/HR

T_{Hbi} = 428 °F

T_{Hbo} = 1193 °F

P_{Nbi} = 371 psia

P_1 = 304 psia

P_2 = 293 psia

P_{Nbo} = 203 psia

ΔP_B = 168 psi

ΔP_{PH} = 67 psi

ΔP_x = 11 psi

ΔP_{PL} = 78 psi

ΔP_{UPL} = 90 psi

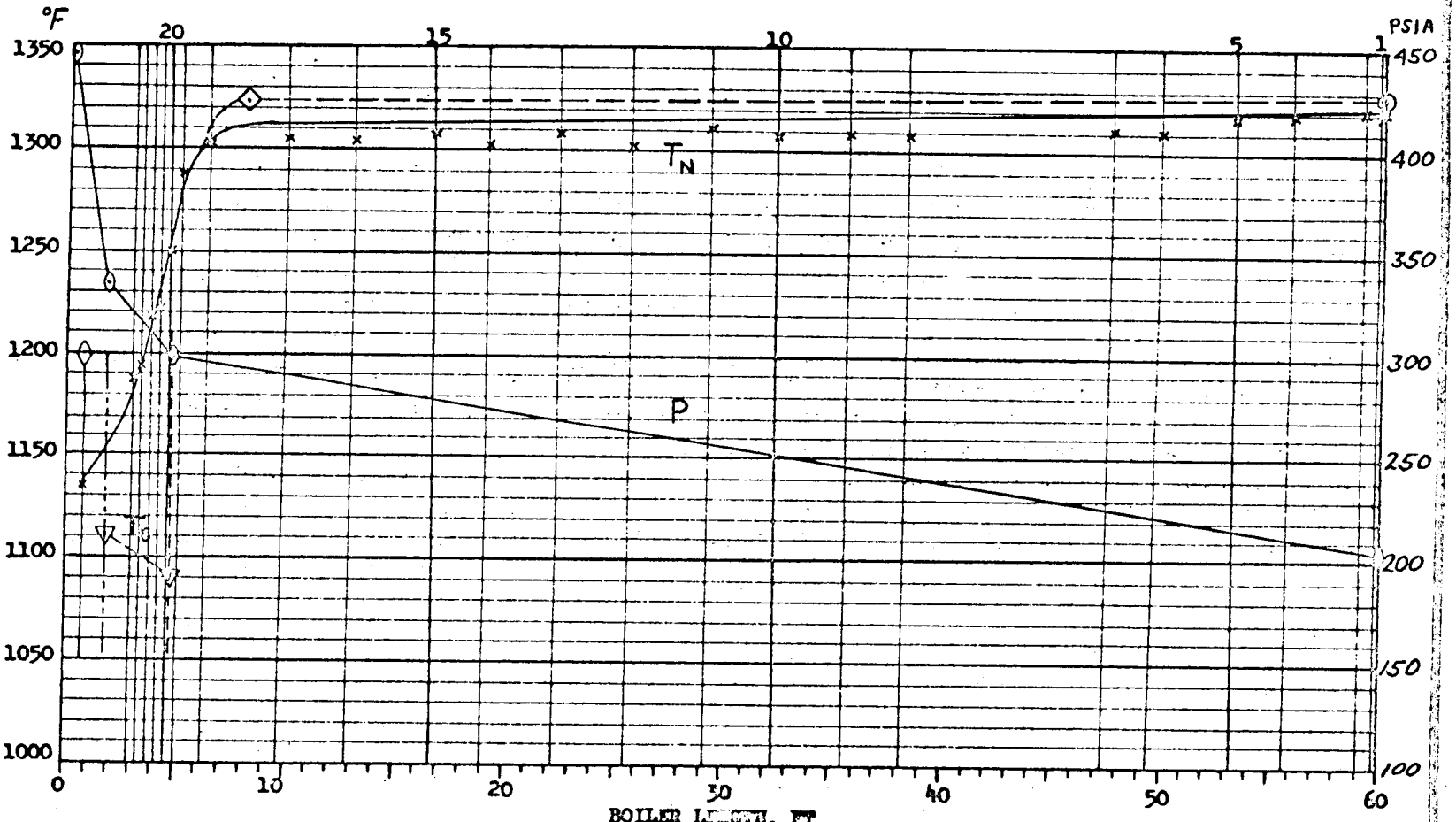
CL-4 BOILER MaK TEMPERATURE PROFILE

DATE 5-19-65

TIME 1431

RUN NO. 8-14

Fig. C-24



PLUG INSERT: *6
W (p x ΔL)$_{PH}$ = ⅛" x 15"
W (p x ΔL)$_{V}$ = 1½" x 36"

W_N = 2055 LB/HR
T_{Nbi} = 1328 °F
T_{Nbo} = 1135 °F
ΔT_N = 193 °F

W_H = 512 LB/HR
T_{Hbi} = 438 °F
T_{Hbo} = 1250 °F

P_{Nbi} = 446 psia
P_1 = 334 psia
P_2 = 299 psia
P_{Nbo} = 204 psia

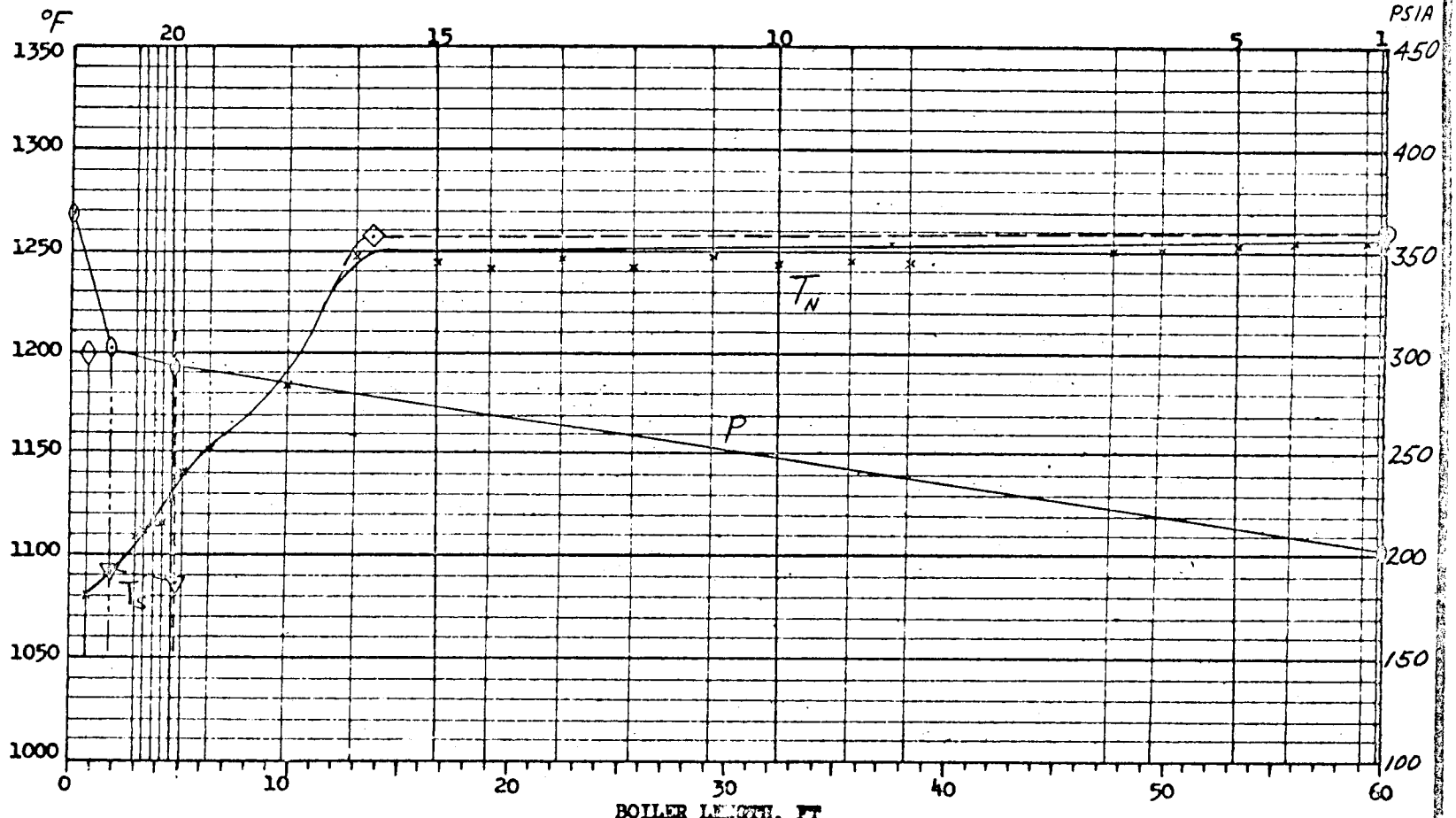
ΔP_B = 242 psi
ΔP_{PH} = 112 psi
ΔP_X = 35 psi

ΔP_{PL} = 147 psi
ΔP_{UPL} = 95 psi

CL-4 BOILER MaX TEMPERATURE PROFILE

DATE 5-19-65
TIME 1610
RUN NO. 8-15

Fig. C-25



PLUG INSERT: *6

$W_{(p \times \Delta L)_{PH}}$ = 1/8" x 15"

$W_{(p \times \Delta L)_V}$ = 1½" x 36"

W_N = 2055 LB/HR

T_{Nbi} = 1260 °F

T_{Nbo} = 1080 °F

ΔT_N = 180 °F

W_H = 496 LB/HR

T_{Hbi} = 435 °F

T_{Hbo} = 1195 °F

P_{Hbi} = 369 psia

P_1 = 302 psia

P_2 = 293 psia

P_{Hbo} = 201 psia

ΔP_B = 168 psi

ΔP_{PH} = 67 psi

ΔP_x = 9 psi

ΔP_{PL} = 76 psi

ΔP_{UPL} = 92 psi

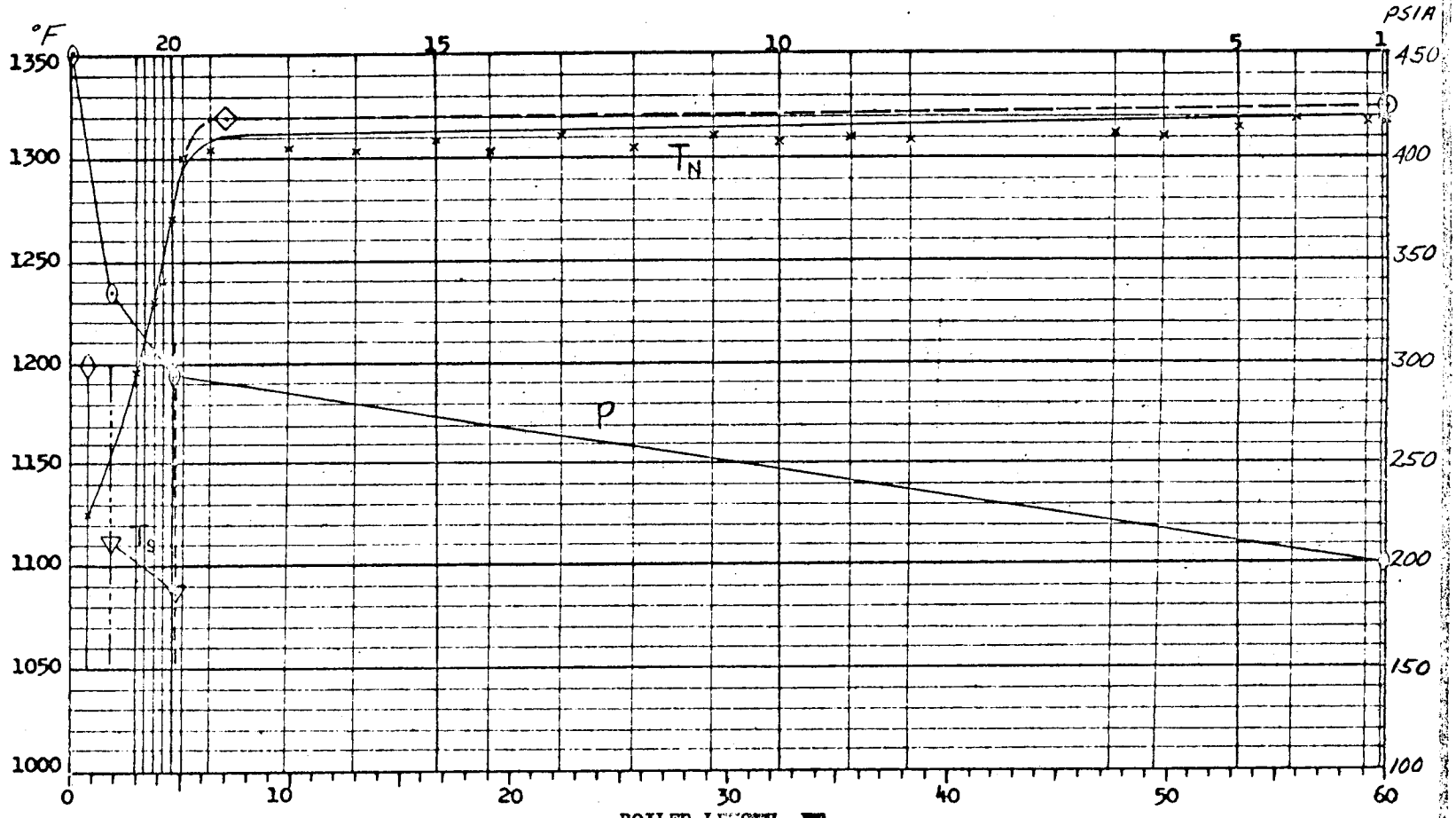
CL-4 BOILER MAX TEMPERATURE PROFILE

DATE 5-19-65

TIME 1725

RUN NO. 8-16

Fig. C-26



PLUG INSERT: #6

$W\ (p \times \Delta L)_{PH}$ = 1/8" × 15"

$W\ (p \times \Delta L)_{v}$ = 1½" × 36"

W_N = 2070 LB/HR

T_{Nbi} = 1325 °F

T_{Nbo} = 1126 °F

ΔT_N = 199 °F

W_H = 493 LB/HR

T_{Hbi} = 435 °F

T_{Hbo} = 1250 °F

P_{Hbi} = 451 psia

P_1 = 335 psia

P_2 = 295 psia

P_{Hbo} = 200 psia

ΔP_B = 251 psi

ΔP_{PH} = 116 psi

ΔP_x = 40 psi

ΔP_{PL} = 156 psi

ΔP_{UPL} = 95 psi

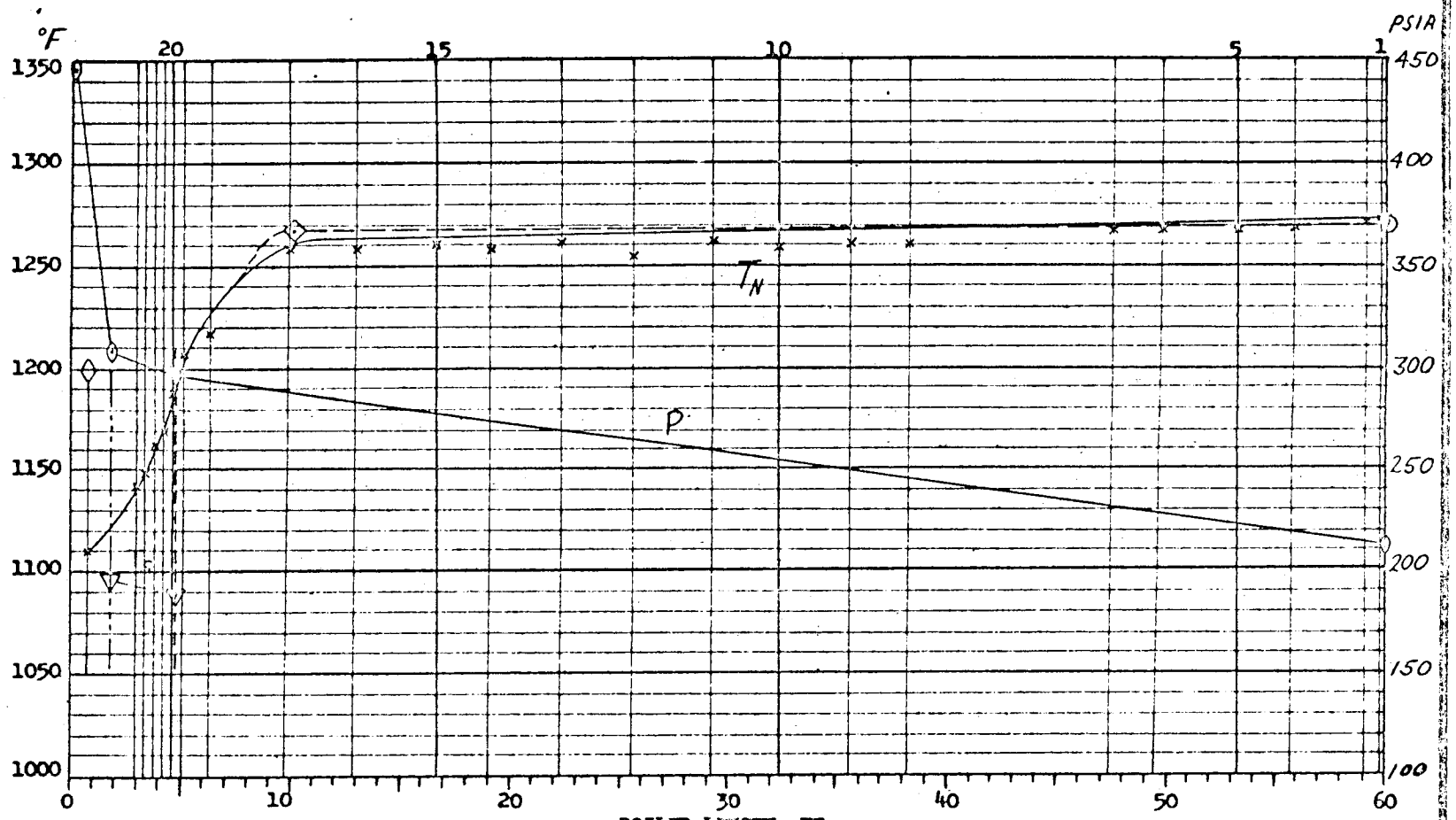
DATE 5-19-65

TIME 1910

RUN NO. 8-17

CL-4 BOILER MaK TEMPERATURE PROFILE

Fig. C-27



PLUG INSERT: *7

W_N = 2040 LB/HR W_H = 462 LB/HR P_{Hbi} = 346 psia ΔP_B = 134 psi ΔP_{PL} = 49 psi

$W\,(p \times \Delta L)_{PH}$ = .17" x 15" T_{Nbi} = 1270 °F T_{Hbi} = 440 °F P_1 = 308 psia ΔP_{PH} = 38 psi ΔP_{UPL} = 85 psi

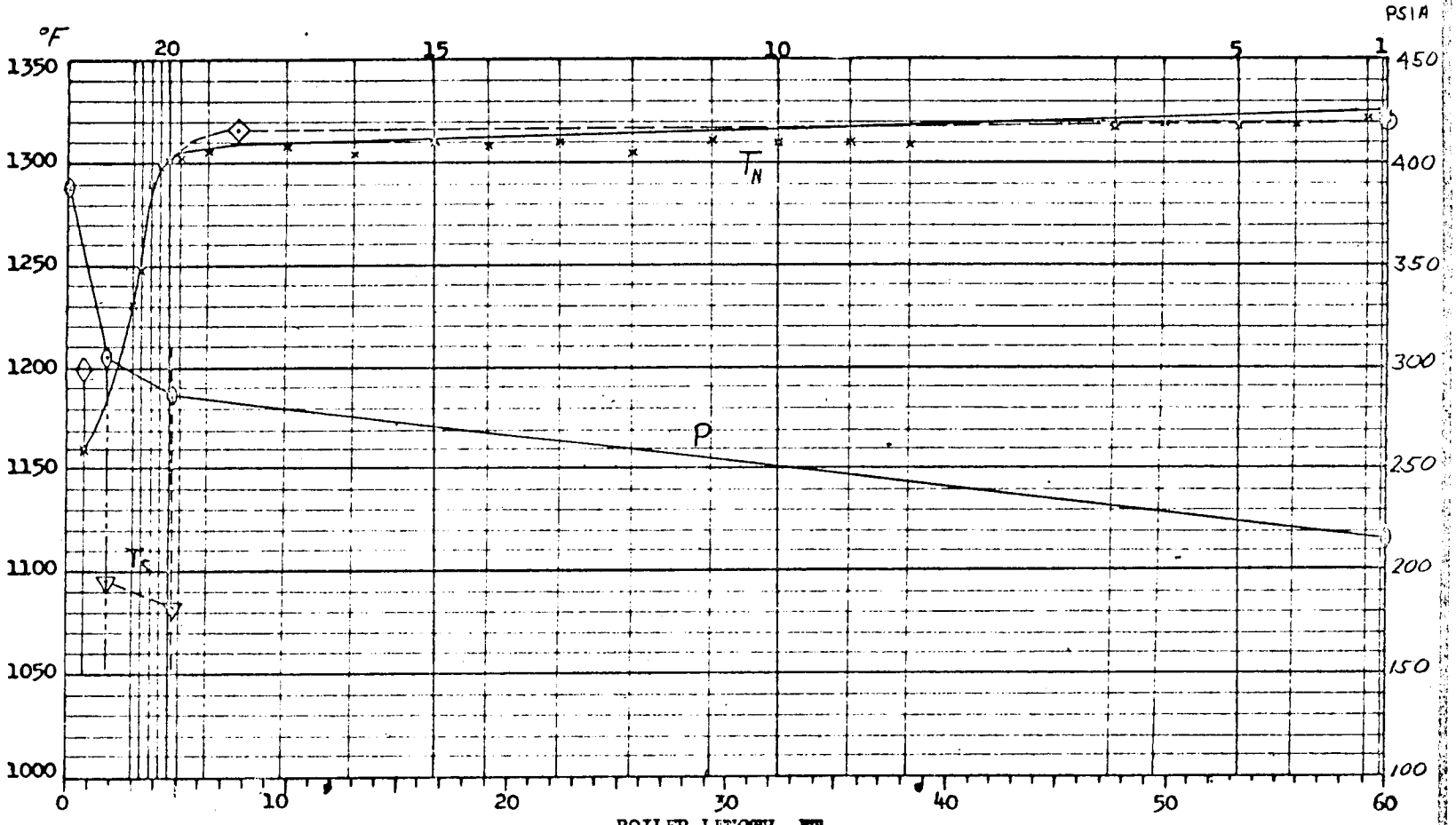
$W\,(p \times \Delta L)_v$ = 1½" x 24" T_{Nbo} = 1110 °F T_{Hbo} = 1200 °F P_2 = 297 psia ΔP_x = 11 psi

ΔT_N = 160 °F P_{Hbo} = 212 psia

DATE 6-2-65
TIME 1047
RUN NO. 10-2

CL-4 BOILER NaK TEMPERATURE PROFILE

Fig. C-28



PLUG INSERT: # 7

$W\ (p \times \Delta L)_{PH}$ = .17" x 15"

$W\ (p \times \Delta L)_{V}$ = 1½" x 24"

W_N = 2040 LB/HR

T_{Nbi} = 1320 °F

T_{Nbo} = 1160 °F

ΔT_N = 160 °F

W_H = 452 LB/HR

T_{Hbi} = 440 °F

T_{Hbo} = 1245 °F

P_{Hbi} = 389 psia

P_1 = 305 psia

P_2 = 287 psia

P_{Hbo} = 216 psia

ΔP_B = 173 psi

ΔP_{PH} = 84 psi

ΔP_x = 18 psi

ΔP_{PL} = 102 psi

ΔP_{UPL} = 71 psi

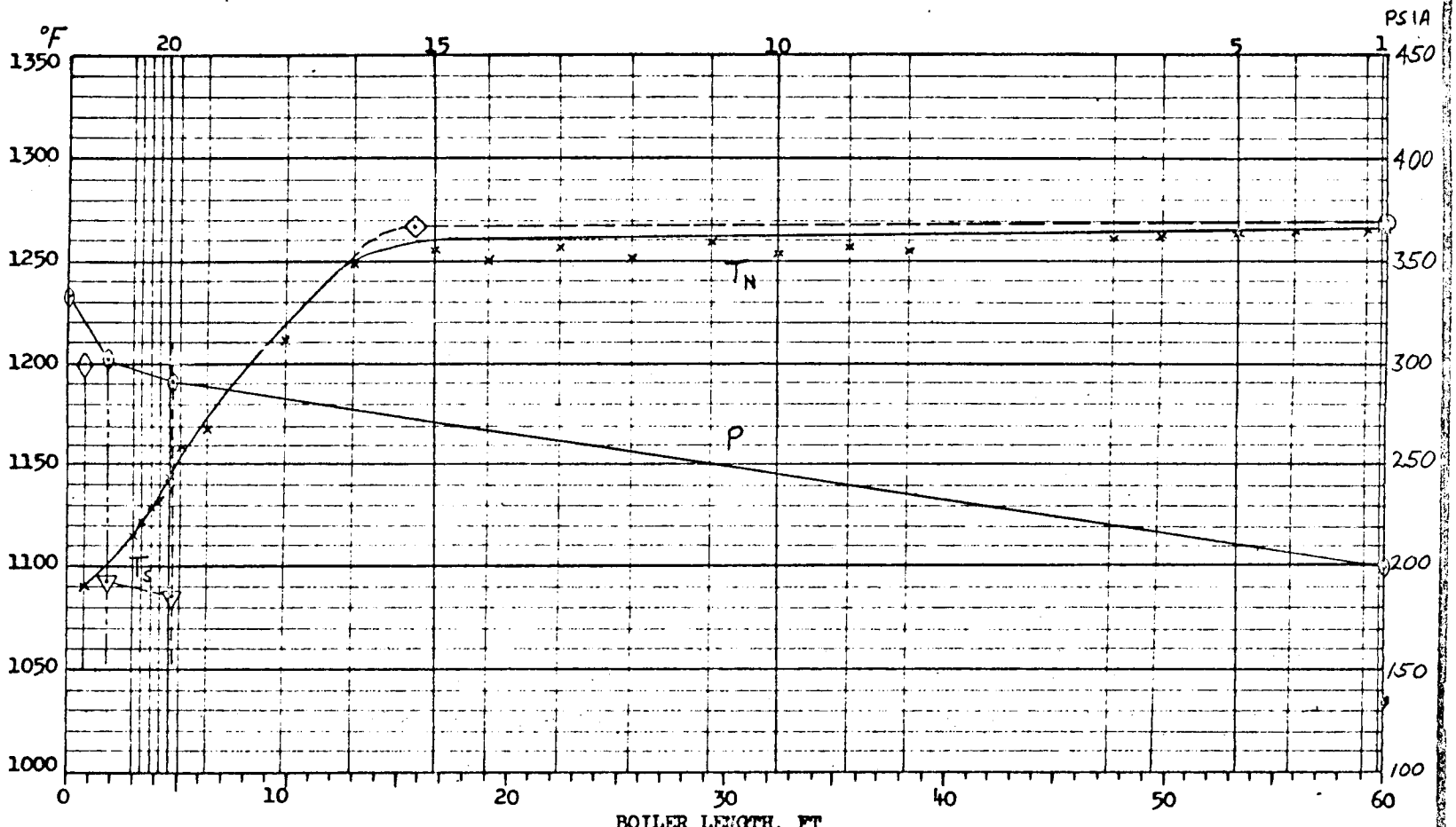
DATE 5-2-65

TIME 1318

RUN NO. 10-3

CL-4 BOILER NaK TEMPERATURE PROFILE

Fig. C-29



PLUG INSERT: #7

$W\ (p \times \Delta L)_{PH}$ = .17" x 15"

$W\ (p \times \Delta L)_{V}$ = 1½" x 24"

W_N = 2040 LB/HR

T_{Nbi} = 1270 °F

T_{Nbo} = 1090 °F

ΔT_N = 180 °F

W_H = 511 LB/HR

T_{Hbi} = 445 °F

T_{Hbo} = 1200 °F

P_{Hbi} = 333 psia

P_1 = 302 psia

P_2 = 291 psia

P_{Hbo} = 199 psia

ΔP_B = 134 psi

ΔP_{PH} = 31 psi

ΔP_x = 11 psi

ΔP_{PL} = 42 psi

ΔP_{UPL} = 92 psi

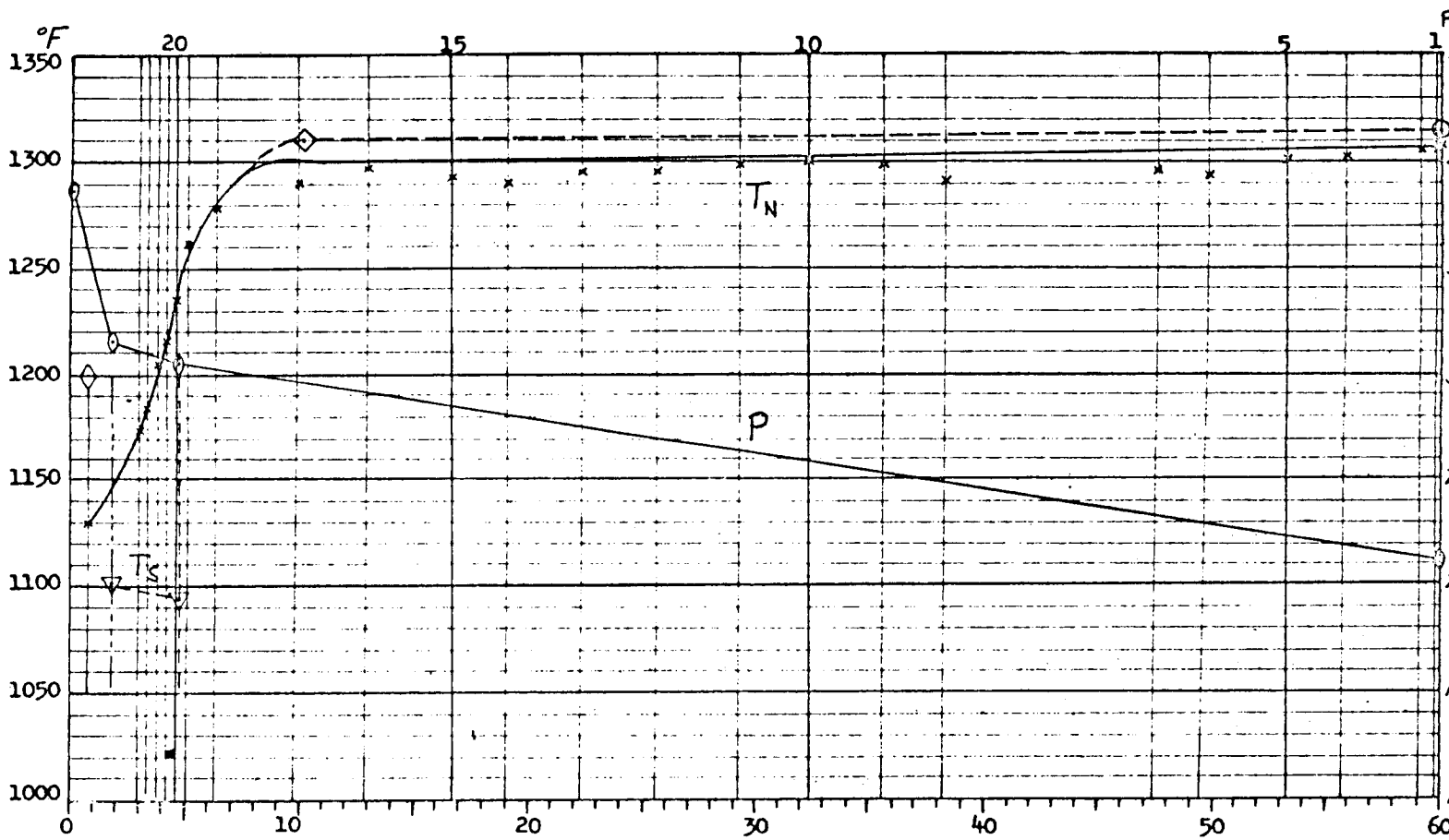
CL-4 BOILER NaK TEMPERATURE PROFILE

DATE 6-2-65

TIME 1550

RUN NO. 10-4

Fig. C-30



PLUG INSERT: #7

$W\ (p \times \Delta L)_{PH}$ = .17" x 15"

$W\ (p \times \Delta L)_{V}$ = 1½" x 24"

W_N = 2050 LB/HR

T_{Nbi} = 1315 °F

T_{Nbo} = 1130 °F

ΔT_N = 185 °F

W_H = 517 LB/HR

T_{Hbi} = 445 °F

T_{Hbo} = 1245 °F

P_{Hbi} = 387 psia

P_1 = 316 psia

P_2 = 306 psia

P_{Hbo} = 212 psia

ΔP_B = 175 psi

ΔP_{PH} = 71 psi

ΔP_x = 10 psi

ΔP_{PL} = 81 psi

ΔP_{UPL} = 94 psi

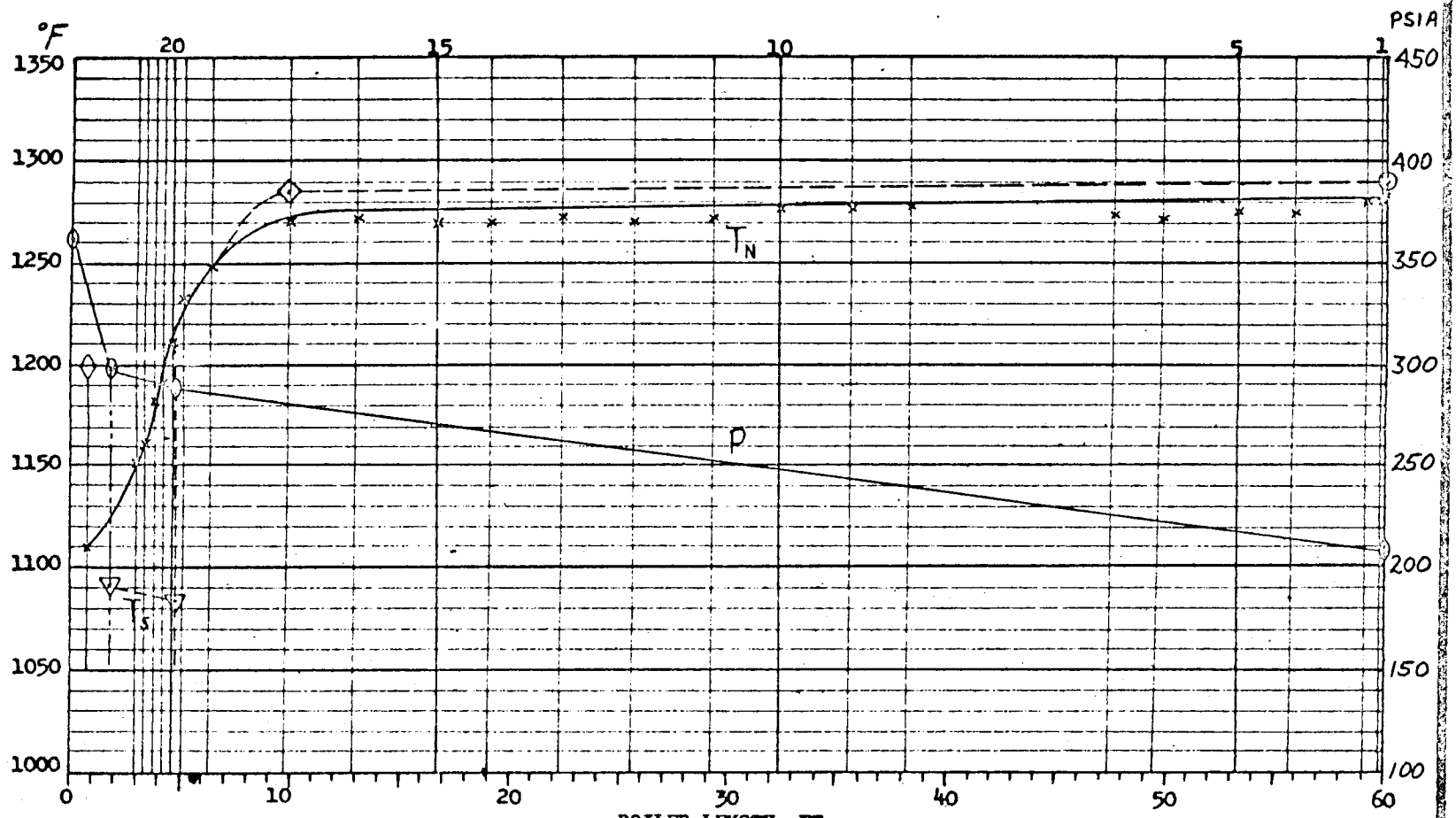
CL-4 BOILER NaK TEMPERATURE PROFILE

DATE 6-3-65

TIME 0825

RUN NO. 10-5

Fig. C-31



PLUG INSERT: * 7

$W\ (p \times \Delta L)_{PH}$ = .17" x 15"

$W\ (p \times \Delta L)_{V}$ = 1½" x 24"

W_N = 2040 LB/HR

T_{Nbi} = 1290 °F

T_{Nbo} = 1110 °F

ΔT_N = 180 °F

W_H = 504 LB/HR

T_{Hbi} = 445 °F

T_{Hbo} = 1220 °F

P_{Hbi} = 362 psia

P_1 = 299 psia

P_2 = 289 psia

P_{Hbo} = 207 psia

ΔP_B = 155 psi

ΔP_{PH} = 63 psi

ΔP_x = 10 psi

ΔP_{PL} = 73 psi

ΔP_{UPL} = 82 psi

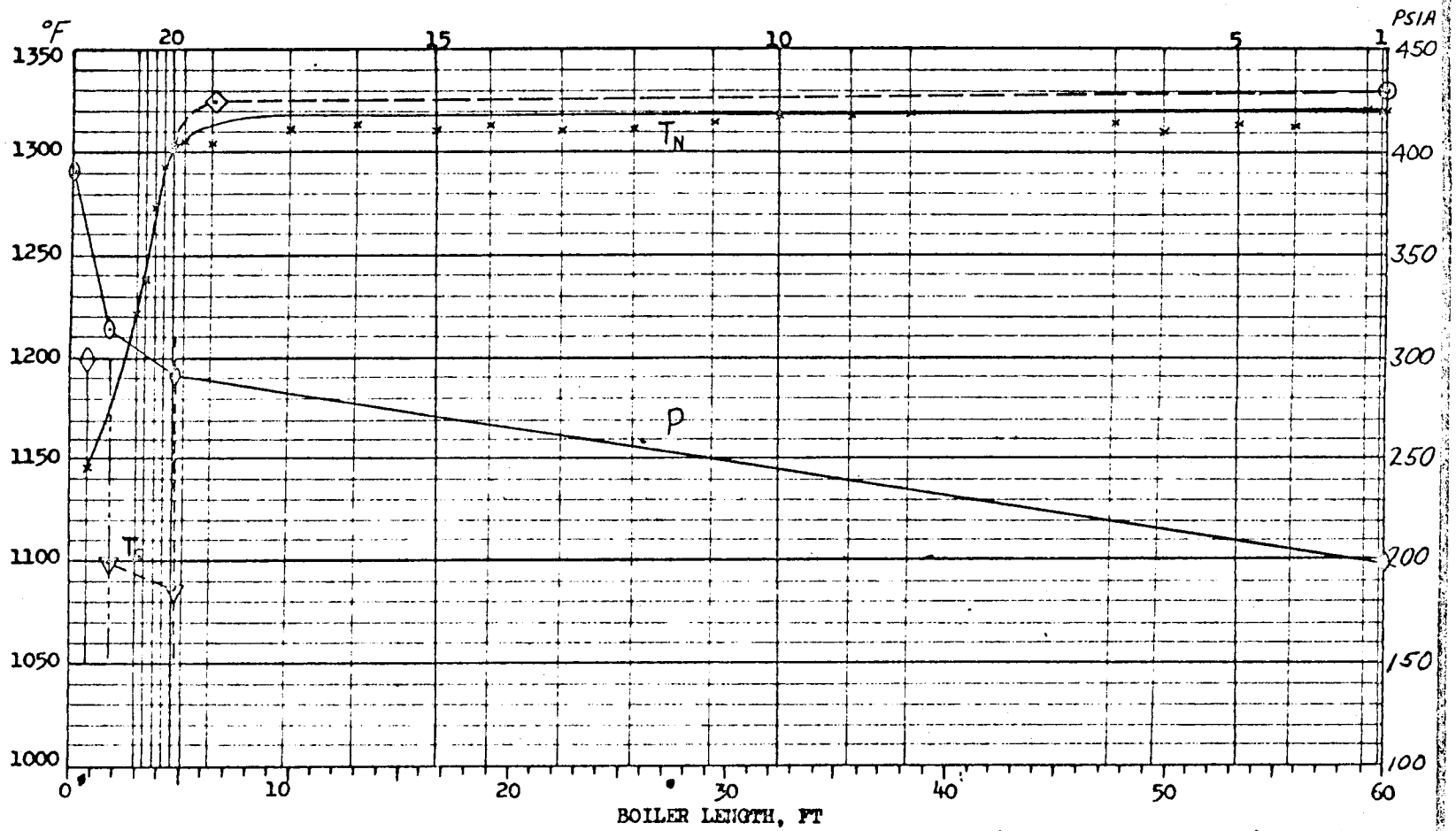
DATE 6-3-65

TIME 1121

RUN NO. 10-6

CL-4 BOILER NaK TEMPERATURE PROFILE

Fig. C-32



PLUG INSERT: #7

$W\ (p \times \Delta L)_{PH}$ = .17" x 15"

$W\ (p \times \Delta L)_{v}$ = 1½" x 24"

W_N = 2040 LB/HR

T_{Nbi} = 1330 °F

T_{Nbo} = 1145 °F

ΔT_N = 185 °F

W_H = 517 LB/HR

T_{Hbi} = 445 °F

T_{Hbo} = 1255 °F

P_{Hbi} = 391 psia

P_1 = 314 psia

P_2 = 291 psia

P_{Hbo} = 198 psia

ΔP_B = 193 psi

ΔP_{PH} = 77 psi

ΔP_x = 23 psi

ΔP_{PL} = 100 psi

ΔP_{UPL} = 93 psi

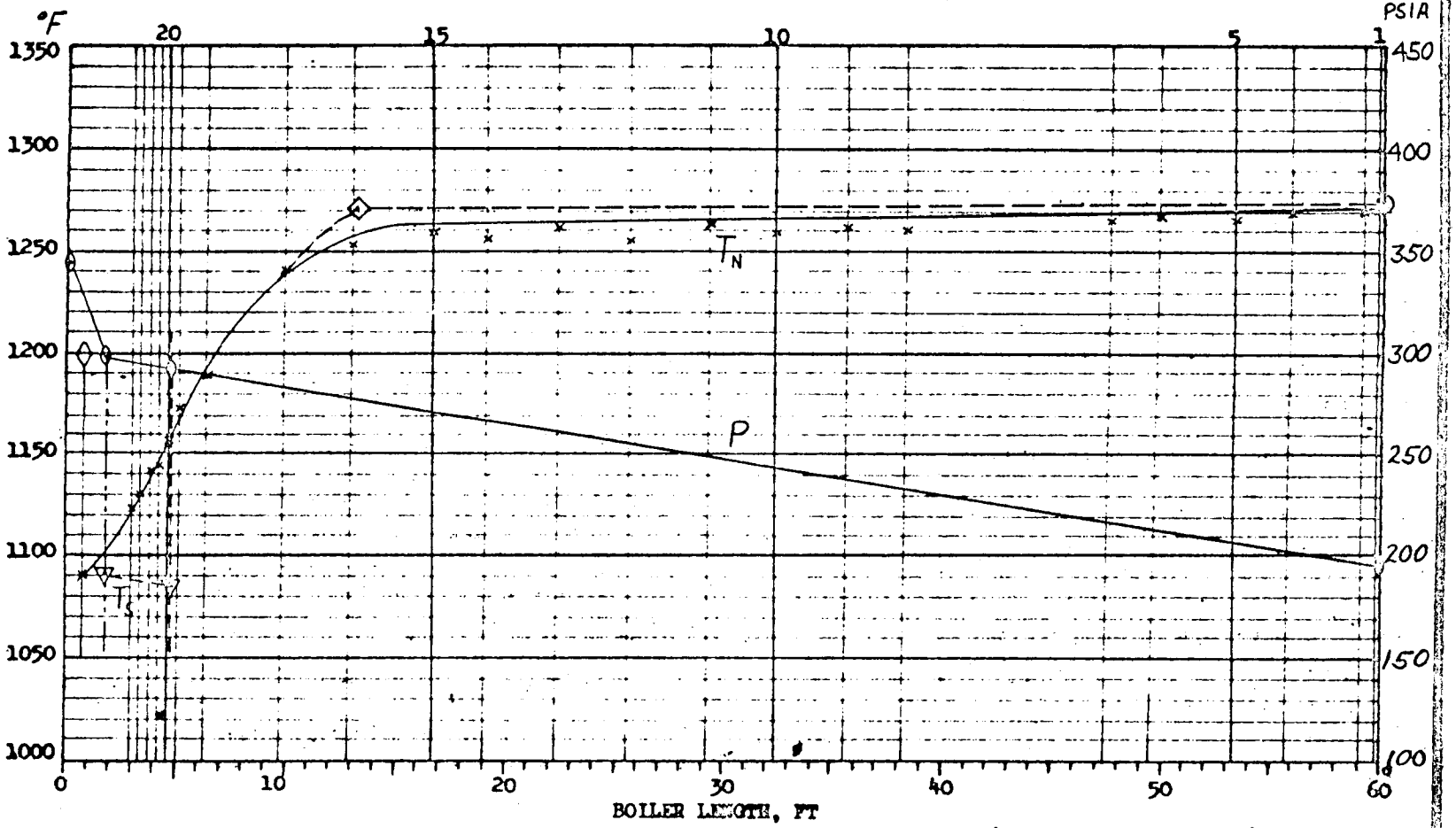
DATE 6-3-65

TIME 1310

RUN NO. 10-7

CL-4 BOILER NaK TEMPERATURE PROFILE

Fig. C-33



PLUG INSERT: * 7

$W_{(p \times \Delta L)_{PH}}$ = .17" x 15"

$W_{(p \times \Delta L)_{PL}}$ = 1½" x 24"

W_N = 2040 LB/HR

T_{Nbi} = 1275 °F

T_{Nbo} = 1090 °F

ΔT_N = 185 °F

W_H = 520 LB/HR

T_{Hbi} = 500 °F

T_{Hbo} = 1210 °F

P_{Hbi} = 344 psia

P_1 = 299 psia

P_2 = 292 psia

P_{Hbo} = 195 psia

ΔP_B = 149 psi

ΔP_{PH} = 45 psi

ΔP_x = 7 psi

ΔP_{PL} = 52 psi

ΔP_{UPL} = 97 psi

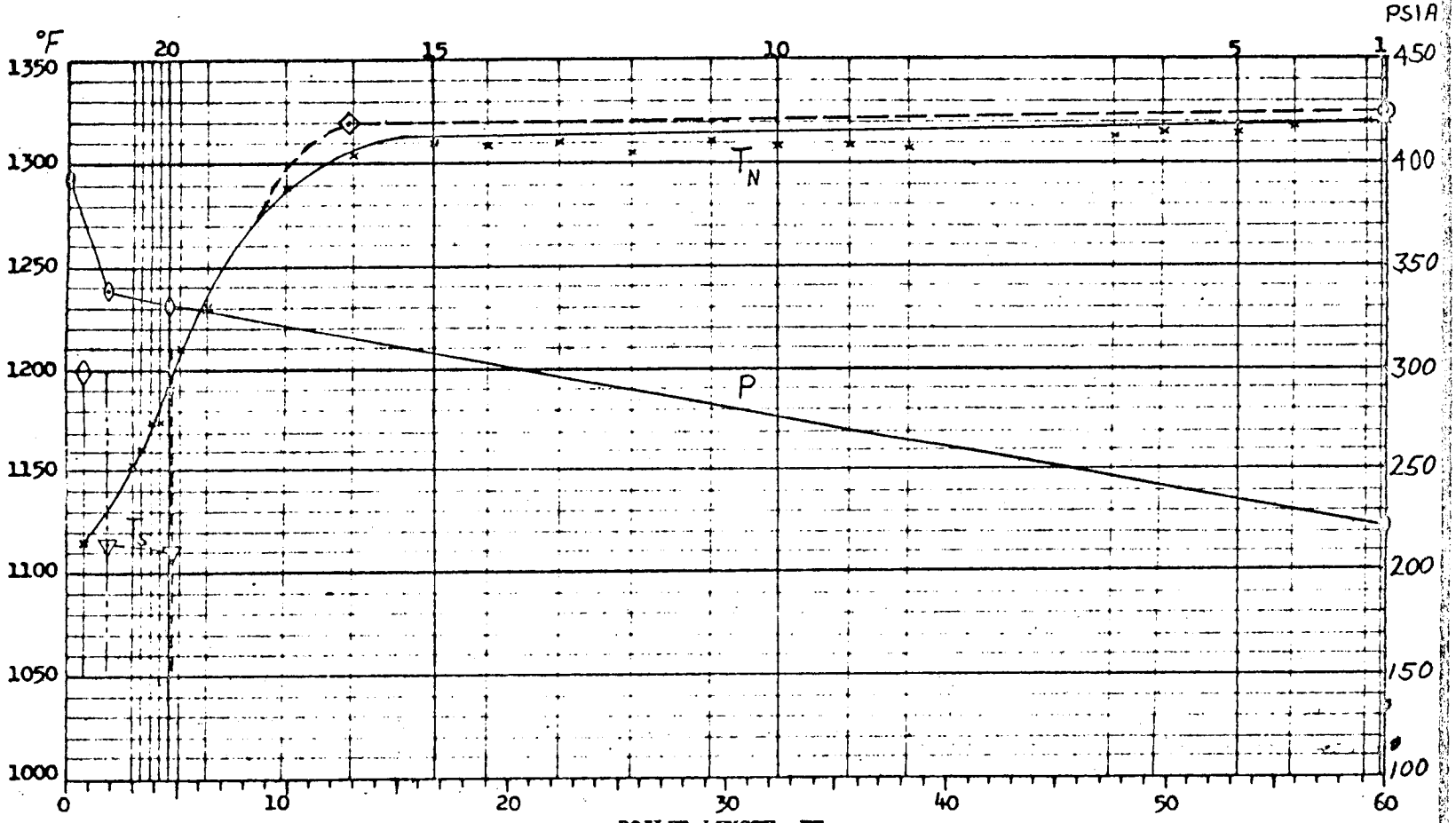
CL-4 BOILER MAX TEMPERATURE PROFILE

DATE 6-4-65

TIME 0820

RUN NO. 10-8

Fig. C-34



PLUG INSERT: * 7

$W\,(p \times \Delta L)_{PH}$ = .17" x 15"

$W\,(p \times \Delta L)_{v}$ = 1½" x 24"

W_N = 2040 LB/HR
T_{Nbi} = 1325 °F
T_{Nbo} = 1115 °F
ΔT_N = 210 °F

W_H = 590 LB/HR
T_{Hbi} = 500 °F
T_{Hbo} = 1260 °F

P_{Hbi} = 393 psia
P_1 = 339 psia
P_2 = 332 psia
P_{Hbo} = 223 psia

ΔP_B = 170 psi
ΔP_{PH} = 54 psi
ΔP_x = 7 psi

ΔP_{PL} = 61 psi
ΔP_{UPL} = 109 psi

DATE 6-4-65
TIME 1130
RUN NO. 10-9

CL-4 BOILER WAK TEMPERATURE PROFILE

Fig. C-35